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STATISTICAL ANALYSIS OF PDC DRILL BITS RUNNINGS AND THEIR LONGEVITY PREDICTION

T.A. Prigorovskaya
Ivano-Frankivsk National Technical University of Oil and Gas
Ivano-Frankivs'k, Ukraine
e-mail: prigorovska@nung.edu.ua

Abstract. *Practice of drilling shows that modern drilling tools and the equipments using needs proper models of descriptive statistics for running results forecasting and optimization of initial drilling parameters. Methodological and practical questions of regression models application for drilling are probed at this article. Besides, it was analyzed the statistical data of PDC drill bits penetrations on the oil and gas fields of Ukraine and world, and probability of non-failure operation was calculated.*

Keywords: *PDC drill bits, rate of penetration, mechanical drilling speed, reliability, regression, statistical model, correlation*

Today it was accumulated a lot of actual data of drill bits runnings. As a rule, these data are represented at the drilling reports, and they form the base for statistical modeling of the drilling. It is well-known, that experimental data of drill bit runnings don't correspond to the fields drilling data, so theoretical drilling models don't match to the practical applications, even if drilling models imitate downhole conditions.

Drilling data analysis show possible increasing of rate of penetration or drilling time because of rational dill bits selection and drilling modes observation. That's why fields drilling data of the real bits running have be the main base for statistical analys and modeling.

So, purpose ot this article is the analysis of the statistical methods usage for PDC drill bits runnings modeling and their longevity prediction.

Main difficult of the statistical modeling is the basic data separation and nessesarity of complicated work for their selection, processing, etc.

So, these facts can explaine that modern models of drilling, rate of penetration and longivity prediction aren't described at the literature.

Main stages of drill bits running modeling are:

- Statistical research of the factors, which influence to the ROP (rate of penetration), drilling speed, longivity, etc.;
- Basic information processing;
- Preliminary data grouping;
- Choising of kind of regression model and it's working out;
- Descriptive statistics, correlation estimation, etc;
- Developed model adequacy estimation.

For modeling and analysis it was selected the drilling reports data from the Ukrainian and Western Siberia oil/gas fields. Rate of penetration, drilling speed, drilling time were analyzed. Initial data were divided into two parts: runnings at the oil/gas fields of Ukraine (for domestic manufactured and imported drill bits) and runnings at the world oil/gas fields.

Drill bits runnings are essentially differs for oil/gas fields of post-USSR and world ones. For instance, average ROP for drill bits produced by Smith International Inc is 1067.5 meters [5]. The most interesting achievement was presented by the PDC drill bit produced by Smith – drill bit Bc75px - bicentric 8,375 inc: ROP 4474 м, drilling speed – 24,2 m/h, region of drilling – Oman, drilled rocks weren't specified. ROP for another types of PDC drill bits were 120-2250 m depends on the region of drilling and drilling equipment.

Average ROP for domestic manufactured drill bits (produced by the Institute of the Super Hard Materials) n Ukraine oil fields is 38.4 m/h. They were drilled soft rocks and soft rocks with medium hard streaks. Drilling regimes: max loading –14 kN, minimal loading – 1 kN, promptness- 40-135 revos/min.

PDC drill bits, which were used for malms, dolomites, etc (in other words, medium-hard rocks with abrasive or hard seams), showed worth running results: average ROP- 2m/h, (downhole turbine motor and rotary drilling, revo- 40-135). Drill bits runned on Kobzivske, Bilske, Berezivske and Abazivske oil fields, intervals – more then 2000 meters.

Such data difference is explaining by the essential difference of drilling technology, drilling regimes, etc. Besides, the analysis was carried out for PDC drill bit running only on Ukraine oil field for domestic manufactured and imported drill bits, because of the difference in their design, materials, technology, etc.

So, all data were divided into 3 groups for modeling:

1. sample of drill bits, produced by Reed-Hycalog and runned on the Ukrainian fields, sample size 190;

2. sample of domestic produced drill bits (Institute of the Super Hard Materials) running on the Ukrainian fields, sample size 145;

3. sample of drill bits running on the Siberian fields (Russian Federation), drill bits were produced by Smith Inc., sample size 256.

Generalized data of all samples showed that the main causes of PDC drill bits wearing are: wearing of chisels – 17 %, chisel breaking – 30 %, chisel shearing – 31 %, chisel falling – 3 %, no wearing 19 % (Fig. 1). So, technological problems of bit's production are the cause of their failure in 53 % cases.

Besides, 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 getting.

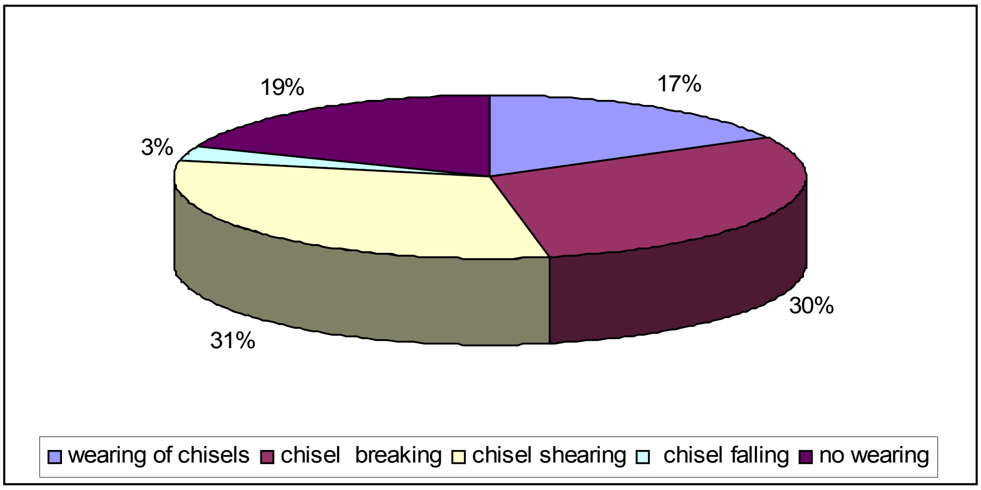

Figure 1. Main characteristics of PDC drill bits wearing

Analysis of the all samples data doesn't show the essential difference of wearing characteristics.

For modeling it was taking off the extreme data (minimum and maximum) from all samples, because of theis possible incorrectness.

For statistical estimation of these data and possible prediction of footage or ROP, based on them, it was decided to choose linear multiple regression in the form of $\mathrm{ROP}=a_0+\sum_{i=1}^{n} a_i x_i$ (x_i – analyzed parameters) due to it's comparative easiness and illustrativeness, where x_1 – characteristics of drilled formation and their influence to the drill bit wearing [2]; x_2 – diameter of drill bit; x_3 – loading; x_4 – promptness; x_5 – volume of drilling mud flushing; x_6 – pressure. Certainly, these parameters don't consider all possible influence factors, but they are represented at the drilling reports

For sample 1 (Ukrainian oil/gas fields) it was obtained:

$$\mathrm{ROP}=1.29344\mathrm{x}_1-1.1684\mathrm{x}_2-0.43727\mathrm{x}_3+2.031\mathrm{x}_4- \\ -11.937\mathrm{x}_5-1.6282\mathrm{x}_6-26.1088.$$

Correlation coefficient for this model is 0.3322 – it means that this model is not matching for prediction of ROP. It worth saying that for another statistical models (logarithmic, exponential, polynomial, etc) correlation coefficient wasn't more then 0.4.

For sample 2 (Ukrainian oil/gas fields, drill bits produced by Institute of Super-Hard Materials, Ukraine) it was obtained:

$$ROP=1{,}87\,x_1-1{,}6384\,x_2-0{,}843727\,x_3+5{,}931\,x_4- \\ -25{,}18\,x_5-1{,}7415\,x_6+114{,}488\,.$$

Correlation coefficient for this model is 0.387 – it means that this model is not matching for prediction of ROP.

Table 1. Some data for regression analysis and PDC drill bits modeling, Siberian oil fields

Field/ well	BHA (bottom-hole assembly)	Drilling regimes		Interval of drilling, m		Drilling rates			
		Loading, tonnes	Drilling mud, litres per second			H, m	Time, hours	Tcir, hours	Vmech, m/hour
Urman-skoe, №210, pad №4	295,3 PDC M516LHPX +KLS-292+ DP1-240	3-5	54	305	462	157	4,17	7,00	37,6
Urman-skoe №210, pad №4	295,3 PDC M516LHPX +KLS-292+ DP1-240	4-6	54	462	732	270	7,63	14,27	35,4
Urman-skoe №210, pad №4	295,3 PDC M516LHPX +KLS-292+ DP1-240	4-6	54	732	1051	319	11,45	17,00	27,9
Urman-skoe №210, pad №4	295,3 PDC M516LHPX +KLS-292+ DP1-240	4-6	54	1051	1245	194	7,62	12,22	25,5
Urman-skoe №118, pad №4	295,3 PDC M516LHPX +KLS-292+ DP1-240	3	54	310	468	158	3,7	7,50	42,7
Urman-skoe №118, pad №4	295,3 PDC M516LHPX+KLS-292+ DP1-240	3- 4	54	468	831	363	11,1	17,90	32,7
Urman-skoe №118, pad №4	295,3 PDC M516LHPX +KLS-292+ DP1-240	3- 4	54	831	1150	319	9,2	16,40	34,7
Urman-skoe №103, pad №4	295,3 PDC M516LHPX +KLS-292+ DP1-240	3-4	40	306	336	30	1,23	2,83	24,4

Table 2. Some data for regression analysis and PDC drill bits modeling, Ukrainian oil fields

Drill bit	Field	rock	Drilling interval, m	Average ROP, m	Average drilling time, hours	Average drilling speed,
Drill bit prodused by Reed-Hycalog loading = 4 kN, revo 2.25 c^{-1}, mud flow rate = 35 *l*/s, pressure P = 90 atm						
11 5/8 DS 66	Novo-Ukrainka 121	rock salt	1470-1608	138	26,1	5,28
11 5/8 DS 66	Novo-Ukrainka 121	rock salt	1608-1708	138	43,45	3,17
11 5/8 DS 66	Novo-Ukrainka 121	rock salt	1815-2287	316	135	2,34
11 5/8 DS 66	Novo-Ukrainka 121	rock salt	2620-2682	62	21	2,952
11 5/8 DS 66	Novo-Ukrainka 121	rock salt	3021-3066	45	19,1	2,356
11 5/8 DS 66	Chutovo -60	rock salt	1650-1950	300	183	1,694
11 5/8 DS 66	Chutovo-60	rock salt	1950-2393	443	183	2,42
Drill bit prodused by Institute of SuperHard Materials, Ukraine loading = 7 kN, revo 1.33 c^{-1}, mud flow rate = 17 *l*/s, pressure P = 90 atm						
ІНМ АП 175/140 С	Kobzovskaya -51	Mudstone clay	3331-3374	43	66	0,65
ІНМ АП 214.3 МС	Kobzovskaya 51	aleurolite	3171-3216	45	10,3	4,37
ІНМ АП 214.3 МС	Kobzovskaya-59	aleurolite	3014-3060	46	73	0,63
ІНМ АП 214.3 МС	Tarasovskaya-200	Sandstone mudstone	4537-4547	16	80,3	0,2
ІНМ АП 214.3 МС	Tarasovskaya-200	Sandstone mudstone	4455-4462	7	26,4	0,27
ІНМ АП 214.3 МС	Tarasovskaya-51	salt	2626-3171	545	197,15	2,76
ІНМ АП 165.3/67 С	Kernosovka-1	Dolomite marl	3809-3822	13	71,15	0,18
ІНМ АП 165.3/67 С	Kernosovka-1	Dolomite marl	3860-3863	3	15,3	0,2
ІНМ АП 165.3/67 С	Kernosovka-1	Dolomite marl	3865-3875	10	68,15	0,15
ІНМ АП 165.3/67 С	Kernosovka-1	Dolomite marl	3980-3989	9	65,45	0,14
ІНМ АП 165.3/67 С	Kernosovka-1	Dolomite marl	3896-3906	10	72,45	0,14
ІНМ АП 165.3/67 С	Kernosovka-1	Dolomite marl	3915-3918	3	24	0,13
ІНМ АП 165.3/67 С	Kernosovka-1	Dolomite marl	3924-3931	7	43,3	0,16
ІНМ АП 165.1 С	Kobzovskaya-31	Dolomite marl	3569-3598	29	64,15	0,45
ІНМ АП 165.1 С	Kobzovskaya-31	Dolomite marl	3618-3762	144	288,15	0,5

For sample 3 (Siberian oil/gas fields) it was obtained:

$$\mathrm{ROP} = 2{,}84\,x_1 - 3{,}005\,x_2 - 1{,}567\,x_3 + 6{,}15\,x_4 - 12{,}11\,x_5 - 2{,}872\,x_6 - 119{,}457\ .$$

Correlation coefficient for this model is 0.33 – it means that this model is not matching for prediction of ROP.

Runnings results of these types of drill bits on mudstone, dolomite, malm, etc. are:

– group of the experimental drill bits Volgaburmash PDC 149,2 FD 353M-A34, footage 1100 meters, average ROP 1.8 m/h, time of drilling – 700 hours, medium-hard rock (malm, dolomite), loading 8-10 kN, West-Orenburg oil field;

– group of experimental drill bits Volgaburmash PDC 295,3FD-257M-A27M, footage 1300 meters, average ROP 2.38 m/h, medium-hard rock (malm, dolomite), loading 8-10 kN, West-Orenburg oil field;

– group of experimental drill bits Volgaburmash PDC 293,0 FD-388MH-A44, footage 2000 meters, average ROP 4.35 m/h, medium-hard rock (malm, dolomite), loading 8-10 kN, West-Orenburg oil field

So, obtained statistical models for all three samples aren't matching for prediction of ROP. Besides, for other statistical models (logarithmic, exponential, polynomial, etc) correlation coefficient wasn't more then 0.4. It, probable, can be explained by the incompleteness of all drilling data, drilling technology infringement, etc. So, this way of statistical modeling of drilling is not acceptable because of all factors neglecting, data fragmentation, etc.

For this problem solution it can be proposed two ways. First of them is the increasing of the analyzed factors and essential increasing of the data, accordingly.

But double data increasing don't caused the increasing of the correlation coefficient. So, this way (sample increasing) is not expediently. That's why we can say, that this approach is not acceptable.

Alternative approach is sample decomposition for the concrete drill bit construction. It means that analysis and modeling is carrying out for concrete construction of drill bits. This way allows to take into account all constructive parameters of concrete drill bits. But in this case it is necessary to have enough data for modeling.

For instance, for drill bit 11 5/8 DS 66 (prodused by Read Hycalog, Ukrainian oil fields) it was obtained:

$$\mathrm{ROP} = -10{,}16\,x_1 - 52{,}86\,x_2 + 6{,}71\,x_3 + 150{,}4\,x_4 + 0{,}307\,x_5 + 218{,}2\,x_6 + 972{,}23\ .$$

Correlation coefficient for this model is 0.9999, so it is possible to use proposed model for prediction footage and analyze of drill bit possible running. For imported drill bit was observed direct proportionality between parameters "loading" and footage, and parameters "formation" and footage, other parameters (kind of drilling, bit diameter, promptness, presser, volume of drilling mud) flushing exert mediated influence on the footage. So, modeling for concrete construction of drill bit is more perspective.

The same approach (modeling for concrete construction of drill bit) was used for next analysis. Next stage was the investigating of the studying of drill bit wearing and function of reliability for concrete drill bit. Research hypothesis is: drilling time increasing caused the drilling speed decreasing due to drill bit wearing. The task is to define the character of this relation – in other words – wearing intense [4, 6, 7].

For instance, for drill bit Read Hycalog 11 5/8 DS 66 (Table 2) it was otrained such relations:

– for linear model $V = -0{,}0038\,t + 3{,}8739$, where t – is drilling time.

– for logarithmic model $y = -0{,}9542\ln(t) + 7{,}8243$.

This way maximal value of the correlation coefficient was 0.77. It means that such approch is not appropriate and it is appropriate to consider another factors.

It worth saying that for another drill bits it were developed relations, which correlation coefficients were between 0.1-0.59. So, it means that this hypothesis is not confirmed (Table 3).

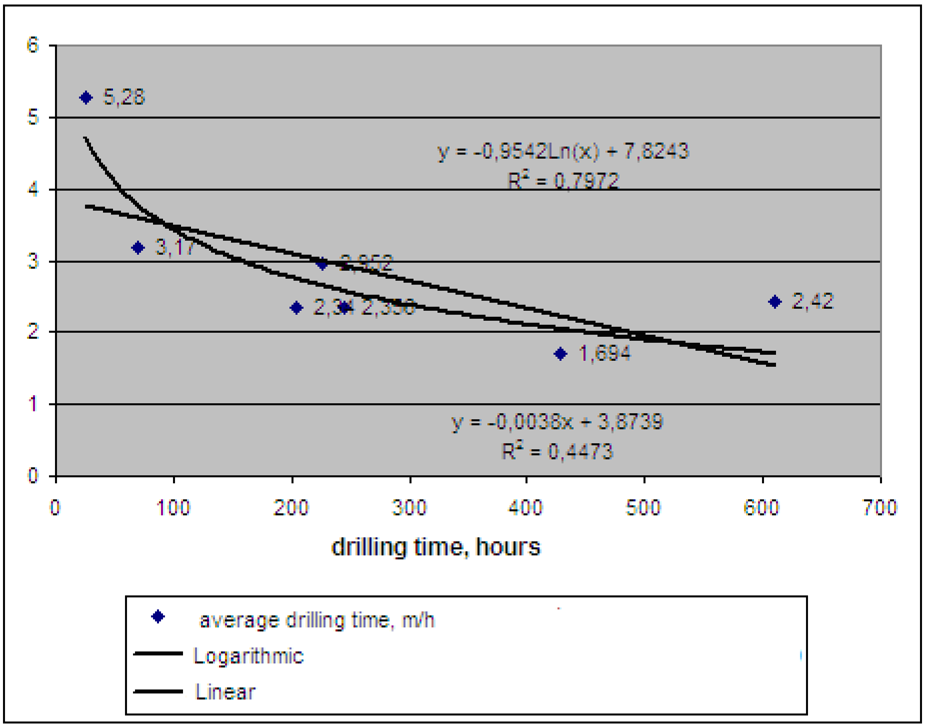

Figure 2. Relation between average drilling speed and time of drilling

All wearing factors are rather complicated task, so it is difficult to define the allowable wearing rate. So, it is arising the task of average theoretical wearing intense (wearing per time) based on the statistical model of drill bit reliability and average data of drill bit durability.

For definition of wearing function it is indispensable to have the variation row of drill bit running and build up the decreasing function of drilling time for concrete construction of drill bit, which were running at the statistically equal conditions (rocks and drilling regimes) – Table 4.

Table 3. Some data for research of relation between drilling time and drilling speed for concrete drill bit

Field	Bush	Hole.	Drill bit			Interval		ROP	Drilling time	Drilling speed
			dia-meter	type	Number	from	to	m	hours	m/h
Verhne Surgutskoe	204	618	215,9	FD355M-A-16	40605	1236	1580	344	9,3	37,0
Verhne Surgutskoe	204	618	215,9	FD355M-A-16	40605	2200	2635	435	30,0	14,5
Verhne Surgutskoe	204	618	215,9	FD355M-A-16	40605	2635	3073	438	27,4	16,0
Verhne Surgutskoe	204	618	215,9	FD355M-A-16	40605	3073	3355	282	41,3	6,8
Verhne Surgutskoe	204	614	215,9	FD355M-A16	0060505	2505	2752	247	32,0	7,7
Verhne Surgutskoe	204	614	215,9	FD355M-A16	0060505	2752	2950	198	29,0	6,8
Verhne Surgutskoe	204	614	215,9	FD355M-A16	0060505	2950	3390	440	37,0	11,9
Verhne Surgutskoe	205	604	215,9	FD355M-A16	0100605	1986	2189	203	10	20,3
Verhne Surgutskoe	205	604	215,9	FD355M-A16	0100605	2334	2700	366	24	15,3
Verhne Surgutskoe	205	604	215,9	FD355M-A16	0100605	2700	2930	230	19	12,1
Verhne Surgutskoe	205	604	215,9	FD355M-A16	0100605	2930	3263	333	26	12,8
Verhne Surgutskoe	206	630	215,9	FD355M-A16	0020905	2065	2250	185	16	11,6
Verhne Surgutskoe	206	630	215,9	FD355M-A16	0020905	2250	2705	455	33	13,8
Verhne Surgutskoe	206	630	215,9	FD355M-A16	0020905	2705	3243	538	28,5	18,9
Verhne Surgutskoe	206	519	215,9	FD355M-A16	0030905	2204	2414	210	28	7,5
Verhne Surgutskoe	206	519	215,9	FD355M-A16	0010805	2414	2765	351	29	12,1
Verhne Surgutskoe	206	519	215,9	FD355M-A16	0091005	2765	3100	335	30	11,2
Verhne Surgutskoe	206	519	215,9	FD355M-A16	0091005	3100	3405	305	23	13,3
Verhne Surgutskoe	206	625	215,9	FD355M-A16	0030605	1134	1200	66	3	22,0
Verhne Surgutskoe	206	625	215,9	FD355M-A16	0030605	1200	1340	140	10,5	13,3
Verhne Surgutskoe	206	625	215,9	FD355M-A16	0060505	1823	2146	323	20	16,3
Verhne Surgutskoe	206	625	215,9	FD355M-A16	0060505	2146	2391	245	35	7,0
Verhne Surgutskoe	206	625	215,9	FD355M-A16	0060505	2391	2650	259	33	7,8
Verhne Surgutskoe	206	522	215,9	FD355M-A16	0010805	884	1023	139	15	9,3

Field	Bush	Hole.	Drill bit			Interval		ROP	Drilling time	Drilling speed
			dia-meter	type	Number	from	to	m	hours	m/h
Verhne Surgutskoe	206	522	215,9	FD355M-A16	0010805	1948	2229	281	23	12,2
Verhne Surgutskoe	206	522	215,9	FD355M-A16	0010805	2229	2550	321	28	11,5
Verhne Surgutskoe	206	522	215,9	FD355M-A16	0010805	2550	2930	380	31,3	12,1
Verhne Surgutskoe	206	522	215,9	FD355M-A16	0040605	2930	3215	285	33	8,6
Verhne Surgutskoe	206	522	215,9	FD355M-A16	0040605	3215	3401	186	26	7,2
Verhne Surgutskoe	206	517	215,9	FD355M-A16	30605	1765	2131	366	21	17,4
Verhne Surgutskoe	206	517	215,9	FD355M-A16	30605	2131	2564	433	27	16,0
Verhne Surgutskoe	206	517	215,9	FD355M-A16	30605	2814	3070	256	21	12,2
Verhne Surgutskoe	206	517	215,9	FD355M-A16	30605	3070	3151	81	8	10,1
Verhne Surgutskoe	206	517	215,9	FD355M-A16	30605	3151	3300	149	18	8,3

Based on these data, longevity functions for concrete drill bits were developed. Variation rows were approximated by the polynomial functions of 5 degree (x – interval, simulated parameter, these parameters was used because of empirical data using and basic intervals weren't equal), but even for the same construction of drill bits it wasn't determinate generalized function of reliability or common tendencies for its development (Fig. 3). Polynomial functions of 5 degree were used, because their correlation coefficient weren't low then 0.99.

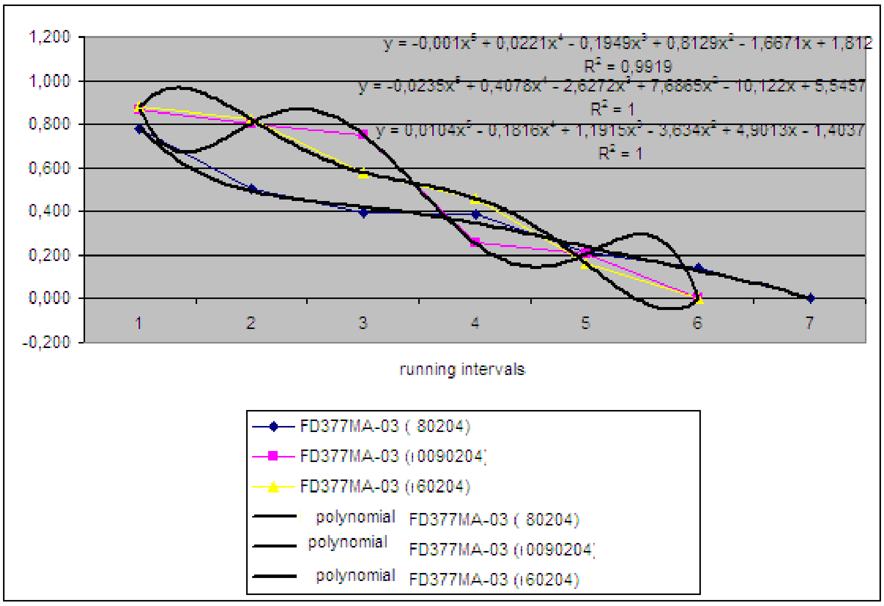

Figure 3

Table 4

Field	Bush	Hole.	Drill bit			Interval		ROP	Drilling time	Dril-ling speed	wear rate	Accumu-lated wear rate	Func-tion of relia-bility
			dia-meter	type	Number	from	to	m	hours	m/h			
Malo-Balykskoe	596	5554	215,9	FD377 MA-03	80204	2131	2447	16	28,2	11,2	0,218	0,218	0,782
Malo-Balykskoe	596	5554	215,9	FD377 MA-03	80204	2447	2952	505	36	14,0	0,278	0,496	0,504
Malo-Balykskoe	596	5554	215,9	FD377 MA-03	80204	2952	3145	193	14,5	13,3	0,112	0,608	0,392
Malo-Balykskoe	596	4622	215,9	FD377 M-A03	80204	2253	2270	17	1	17,0	0,008	0,616	0,384
Malo-Balykskoe	596	4622	215,9	FD377 M-A03	80204	2270	2485	215	22,5	9,6	0,174	0,790	0,210
Malo-Balykskoe	596	4622	215,9	FD377 M-A03	80204	2485	2575	90	9,2	9,8	0,071	0,861	0,139
Malo-Balykskoe	596	4622	215,9	FD377 M-A03	80204	2778	2878	100	18	5,6	0,139	1,000	0,000
Malo-Balykskoe	596	4622	215,9	FD377 M-A03	0090204	2878	3020	142	17,7	8,0	0,132	0,132	0,868
Malo-Balykskoe	596	4622	215,9	FD377 M-A03	0090204	3020	3095	75	8,5	8,8	0,064	0,196	0,804
Malo-Balykskoe	596	4597	215,9	FD377 M-A03	0090204	2152	2230	78	7,1	11,0	0,053	0,249	0,751
Malo-Balykskoe	596	4597	215,9	FD377 M-A03	0090204	2230	3070	840	66	12,7	0,494	0,743	0,257
Malo-Balykskoe	596	4597	215,9	FD377 M-A03	0090204	3070	3125	55	6,8	8,1	0,051	0,794	0,206
Malo-Balykskoe	596	5543	215,9	FD377 M-A03	0090204	2013	2270	257	27,5	9,3	0,206	1,000	0,000
Malo-Balykskoe	596	4622	215,9	FD377 M-A03	0090204	2878	3020	142	17,7	8,0	0,132	0,132	0,868
Malo-Balykskoe	596	4622	215,9	FD377 M-A03	0090204	2878	3020	142	17,7	8,0	0,132	0,132	0,868
Malo-Balykskoe	596	4622	215,9	FD377 M-A03	0090204	3020	3095	75	8,5	8,8	0,064	0,196	0,804
Malo-Balykskoe	596	4597	215,9	FD377 M-A03	0090204	2152	2230	78	7,1	11,0	0,053	0,249	0,751
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Malo-Balykskoe	596	4597	215,9	FD377 M-A03	0090204	3070	3125	55	6,8	8,1	0,051	0,794	0,206
Malo-Balykskoe	596	5543	215,9	FD377 M-A03	0090204	2013	2270	257	27,5	9,3	0,206	1,000	0,000
Malo-Balykskoe	596	4622	215,9	FD377 M-A03	0090204	2878	3020	142	17,7	8,0	0,132	0,132	0,868

Running data show that despite of drill bits worked out at the equal conditions, average ROP, total drilling time were differs for the drill bits of the same constructions and it is impossible to develop reliability function even for the same construction of drill bits.

So, for analytical description of reliability function it is expediently to use the random function, for which operating time between failures is distributed normally:

$$P(\tau > T) = 1 - \frac{1}{\sqrt{2\pi}} \int_{\infty}^{\left(\frac{\tau - C}{\sigma}\right)} e^{\tau^2/2} d\tau ,$$

where τ – time, for which we define probability; T – average drilling time for particular drill bit; C – expectation; σ – medium-square deviation.

For example, for the model 215,9 FD355M-A16 of drill bits, which produced by JSC "VolgaBurMash", runned at Malo-Balykskoe and Verhne-Surgutskoe fields, it was obtained such data of operating times between failures (Table 5) [9].

Table 5. Data of 295,3 FD355M-A16 drill bit running

Number of drill bit	**ROP**	**Drilling time**	**Average drilling speed**
	m	**hours**	**m/h**
002 04 05	573	47	47,34848
010 02 04	672	71	47,92576
0030805	1253	103	61,16262
70605	1270	108,3	71,99616
81005	863	100,5	50,41347
70606	370	18	20,55556
40605	1784	141	82,9391
60505	1712	186	57,58671
100605	1132	79	60,46296
20905	1178	77,5	44,22757
30905	210	28	7,5
10805	1472	126,3	57,19237
91005	640	53	24,42754

Empirical average and dispersion of the operation time are:

$$\begin{cases} C = \dfrac{\sum_{i=1}^{N} t_i}{N} = \dfrac{\begin{pmatrix} 47+71+103+108.3+100.5+18+141 \\ +186+79+77.5+28+126.3+53 \end{pmatrix}}{13} = 87.58 ãîä \\ \sigma_t^2 = \dfrac{\sum_{i=1}^{N}(t_i - C)^2}{N-1} = \dfrac{\begin{pmatrix} (47-87{,}58)^2 + (71-87{,}58)^2 + (103-87{,}58)^2 + \\ +(108.3-87{,}58)^2 + (100.5-87{,}58)^2 + (18-87{,}58)^2 + \\ +(141-87{,}58)^2 + (186-87{,}58)^2 + (79-87{,}58)^2 + \\ +(77.5-87{,}58)^2 + (28-87{,}58)^2 + (126.3-87{,}58)^2 + \\ +(53-87{,}58)^2 \end{pmatrix}}{12} = 2213{,}103 \end{cases}$$

So, probability of no-failure operation for concrete term is:

$$P(\tau > T) = 1 - \Phi\left(\frac{\tau - C}{\sigma}\right),$$

where τ – time, for which we define probability, Φ – Laplace function.

$$P(\tau > T) = 1 - \frac{1}{\sqrt{2\pi}} \int_{\infty}^{\left(\frac{\tau - 87{,}58}{\sqrt{2213{,}103}}\right)} e^{\tau^2/2} d\tau = 1 - \Phi\left(\frac{\tau - 87{,}58}{\sqrt{2213{,}103}}\right).$$

Next stage of modeling is definition of the allowable wearing rate of particular chisels of drill bit. It is well known, that wearing of the chisels is irregular. Central chisels are the most weared, but the peripheral chisels aren't weared, as a rule (Fig. 4, 5). Besides, loading to the drill bit chisel is distributed indefinitely.

So, considering the possible correspondence between wearing rate and curve of normal distribution, we can assume, that loading to the chsisels of drill bit is normally distributed with the density of probability $P = f(x) = \dfrac{P\max}{\sqrt{2\pi}\,\sigma \cdot n} \cdot \exp^{-\frac{(x-a)^2}{2\sigma^2}}$, where x – coordinate of concrete chisel location in projection to the horizontal plate relatively to the most loaded chisels, a – expectation; σ – medium-square deviation of chisel location.

For statistical estimation of loading to the concrete chisel, especially considering symmetry of drill bit, we can assume, that curves of normal distribution in a central part of instrument are imposed. So, loading to the central chisel is not increasing

Figure 4. Photo of runned drill bit Read Hycalog 11 5/8 DS 66

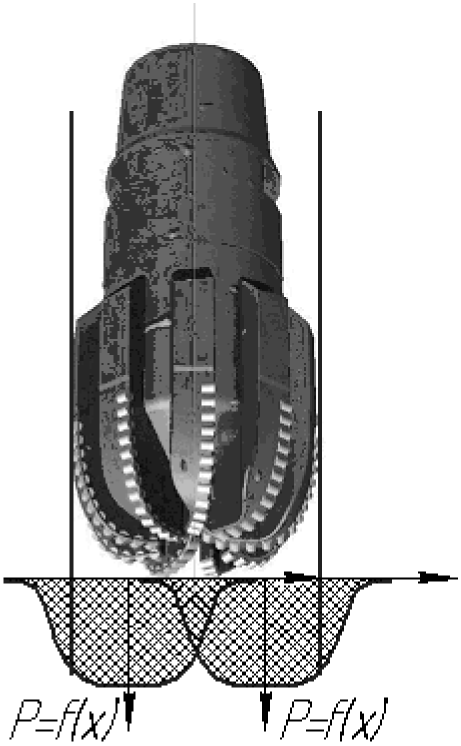

Figure 5. Development of the normal distribution curve

Conclusions

1. Drill bit running results depend on a lot of factors and, as a rule, it is impossible to develop the non-empirical model of the drilling speed, rate of penetration, etc., because of possible random factors influence. Besides, developed non-empirical relatives do not correspond to the field data.

2. Generalized data of all samples showed that the main causes of PDC drill bits wearing are: wearing of chisels – 17 %, chisel breaking 30 %, chisel shearing 31 %, chisel falling – 3 %, no wearing 19 %. So, technological problems of bit's production are the cause of their failure in 53 % cases.

3. It was defined that linear, logarithmic, exponent models aren't appropriated for drill bits running estimation for grouped data: sample of drill bits runned on the Ukrainian fields; sample of domestic produced drill bits running on the Ukrainian fields; sample of drill bits running on the Siberian fields (Russian Federation), drill bits were produced by Smith Inc. Correlation coefficient of all models wasn't more than 0.4. It, probable, can be explained by the unauthenticated of data of drilling, drilling technology infringement, etc.

4. For this problem solution it can be proposed two ways. First of them is the increasing of the analyzed factors and essential increasing of the data, accordingly. But double data increasing don't caused the increasing of the correlation coefficient. So, this way (sample increasing) is not expediently. That's why we can say, that this approach is not acceptable. Alternative approach is sample decomposition for the concrete drill bit construction. It means that analysis and modeling is carrying out for concrete construction of drill bits. This way allows to take into account all constructive parameters of concrete drill bits. But in this case it is necessary to have enough data for modeling. It was developed linear model for concrete instrument.

5. For definition of wearing function it was developed the relation between total drilling time and drilling speed. Research hypothesis is: drilling time increasing caused the drilling speed decreasing due to drill bit wearing. The task is to define the character of this relation – in other words – wearing intense. Such approach is not appropriate and it is appropriate to consider another factors. Running data show that despite of drill bits worked out at the equal conditions, average ROP, total drilling time were differs for the drill bits of the same constructions and it is impossible to develop reliability function even for the same construction of drill bits.

6. Considering the possible correspondence between wearing rate and curve of normal distribution, we can assume, that loading to the chisels of drill bit is normally distributed.

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