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Mirosław Rzyczniak*, Grzegorz Rajchel **

THE ANALYSIS OF TECHNOLOGY OF DRILLING WITH ROLLER BITS ON THE CARPATHIAN FORELAND AREA IN THE YEARS 1995 – 2011***

1. INTRODUCTION

Leading the long-term analysis of change in value of drilling technology parameters and rate of drilling process, enables evaluation of drilling technology, mainly the quality of drilling equipment, and improving the selection of their work-steering parameter.

In order to conduct the research, there were collected results from 776 bit runs, which were made with three-cone bits. All of them had been manufactured by Drilling Equipment and Device Company "GLINIK" [2] on the Carpathian foreland area in Poland in the years 1995 – 2011.

For the statistical analysis there were selected four groups of drills [3], in terms of their diameter and IADC (International Association of Drilling Contractors) [5] code:

1. diameter $D_ś$ = 0,216 m, for drilling in very soft and soft rocks (trial quantity n_p = 470)
2. diameter $D_ś$ = 0,216 m, for drilling in medium hard rocks (trial quantity n_p = 43)
3. diameter $D_ś$ = 0,311 m, for drilling in very soft and soft rocks (trial quantity n_p = 176)
4. diameter $D_ś$ = 0,4445 m, for drilling in very soft and soft rocks (trial quantity n_p = 87)

Selecting groups of drills of the same type used in similar geological condition was a necessary condition for ensuring the correctness of leading analysis.

2. RESEARCH METHODOLOGY

For the selected drilling technology parameters (weight on bit P, rotational speed n, product of unit weight on bit and rotational speed $P_j \cdot n$, drilling mud capacity flow rate Q)

* AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow
** AGH University of Science and Technology, Graduate Faculty Drilling oil and Gas
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and bit performances (rebore H, drilling time T_w, mechanical average drilling rate $v_{śr}$) there were prepared charts showing dispersion of the values depending on the year in which drills were used.

Using the least – squares method, there was estimated linear function of regression, showing, in the best way, the adjustment of measure points to straight regression (straight lines). Dotted lines assign affiance interval.

As the measure of strength between variables there were assumed correlation factors R (tab. 1, tab. 2), which had been calculated from samples, and for which there were conducted significance tests [1] standing the basic hypothesis H_o: $R = 0$ considering the alternative hypothesis H_1: $R \neq 0$. Values of correlation factors from the samples and critical values of correlation factors $R(\alpha, v)$ for v latitude levels at the significance level $\alpha = 0{,}05$, were calculated using the program STATISTICA 10 [4].

Only in groups of drills number 1 and 4 (tab. 1, tab. 2) the result was a relation $|R| > R(\alpha, v)$ for most of the examined relations, which means that in those cases there were no bases to reject the hypothesis of significantly different to 0 values of correlation factors that had been calculated from the samples.

For the purpose of defining to what extend the accepted model explains forming the accounting variable there were calculated values of determination factor R^2 (tab. 1, tab. 2) [6].

In groups of drills number 2 and 3 on the account received dependencies: $|R| < R(\alpha, v)$, it was necessary to assume the basic hypothesis H_o about the lack of correlation between examining variables. It means that in the analyzed period of time there has not been noticed any essential changes of technological parameters and bit performances selected in these groups. For that reason the analysis lead for these groups of bits were not printed in the text of the article, however, the following analysis were lead for groups of bits number 1 and 4.

For the purpose of confirming thesis of the existence of linear dependency between researched variables, there were lead significance tests for the linear regression factor of appointed equations (tab. 1, tab. 2) stating the basic hypothesis H_o: $a = 0$, about different from zero value of the linear regression factor considering the alternative hypothesis H_1: $a \neq 0$ about significantly different from zero value of that factor [1].

The basic hypothesis was verified by comparing the calculations from the sample of statistical value t – Student with the critical statistical values t_α calculated for assumed significance level $\alpha = 0{,}05$ and $v = n - 2$ of latitude levels, in term with the purpose of control the dependency $p\{|t| \geq t(\alpha, v)\} = \alpha$ [1, 4 ,7].

As a result of leading significance tests for the linear regression factor appointed from the samples, there was achieved a dependency $|t| > t(\alpha, v)$ meaning the possibility of acceptance the alternative hypothesis about significantly different from zero value of linear regression factors for most of the functions appointed for groups of bits number 1 and 4 (tab.1, tab. 2). This means that the appointed rectilinear regression equation may appear as a base for predicting values of examining technological parameters and bit performances with chosen equipment in the function of time.

Analysis of the technological parameters and bit performances for diameter $D_ś$ = 0,216 m

As a result of leading analysis of work of bits with diameter $D_ś$ = 0,216 m, produced by "GLINIK", that were used for drilling in very soft and soft rock layers of the Carpathian foreland area there was assumed that during the analyzed period of time (the years of 1995 – 2011) there was appearing a decrease of the weight on bit *P* (tab. 1, fig. 1) with simultaneous increase of the rotational speed *n* (tab. 1, fig. 2). The effect of steering parameters *P* and *n* was a decreasing tendency of normalized product of the weight on bit and the rotational speed $P_j \cdot n$ over the years in which examined drills were exploiting (tab. 1, fig. 3).

There was noticed, however, an increase of the value of drilling mud capacity flow rate *Q* (tab. 1, fig. 4).

This way of steering parameters of drilling technology means that searching for optimum values to counterbalance hydraulic power and mechanical power provided to a bit. Moreover, decreasing the axial pressure may well have been a result from the necessity to limit the tendency to curve the holes from technological reasons.

The effect of using drilling technology parameters was a decrease of rebore *H* (tab. 1, fig. 5) and drilling time T_w (tab. 1, fig. 6) with the passage of time.

There was no notice, however, of any statistically essential changes of average rate of penetration $v_{śr}$ in the analyzed period of time (tab. 1, fig. 7).

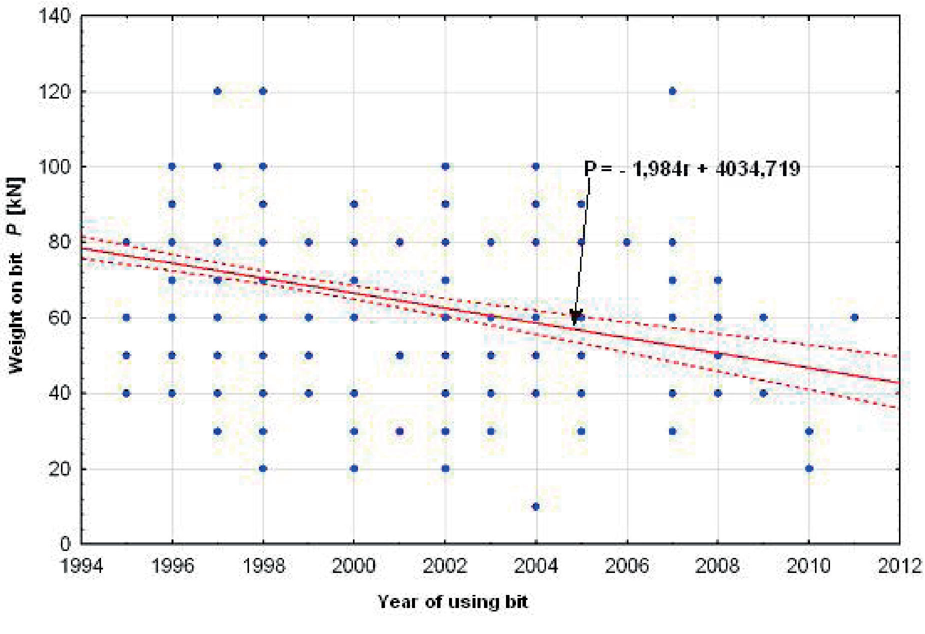

Fig. 1. Chart showing a dispersion of measure points and regression line, dependent on weight on bit and year of using bits with diameter 0,216 m

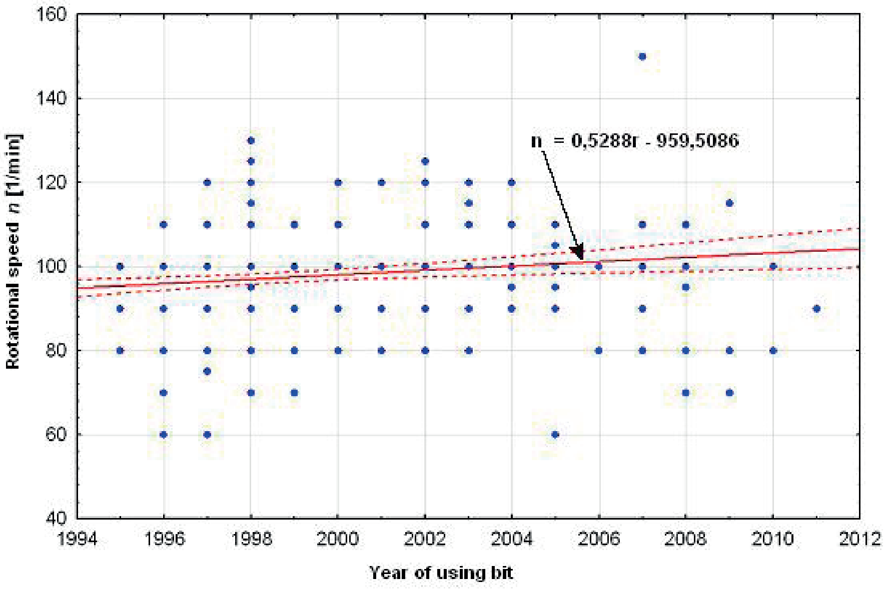

Fig. 2. Chart showing a dispersion of measure points and regression line, dependent on rotational speed and year of using bits with diameter 0,216 m

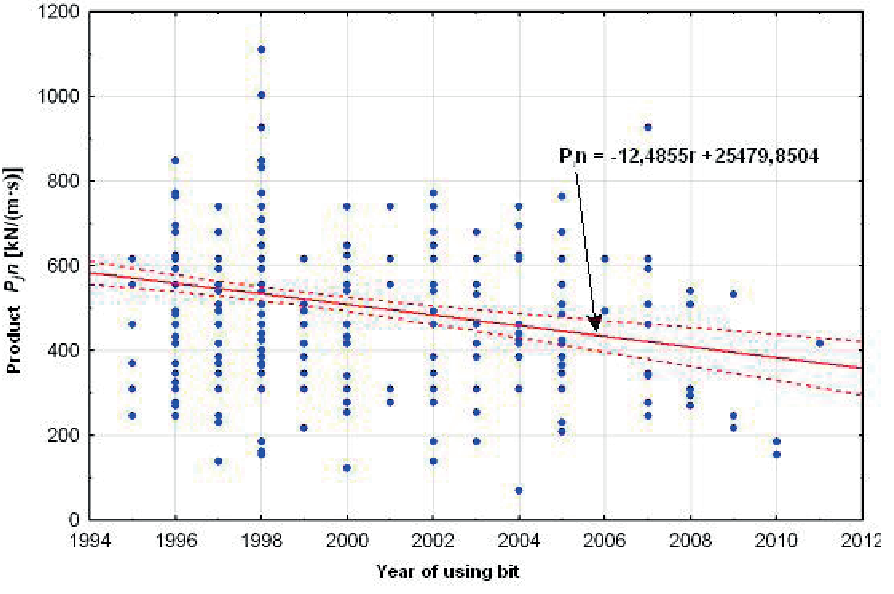

Fig. 3. Chart showing a dispersion of measure points and regression line, dependent on product of unit weight on bit and rotational speed and year of using bits with diameter 0,216 m

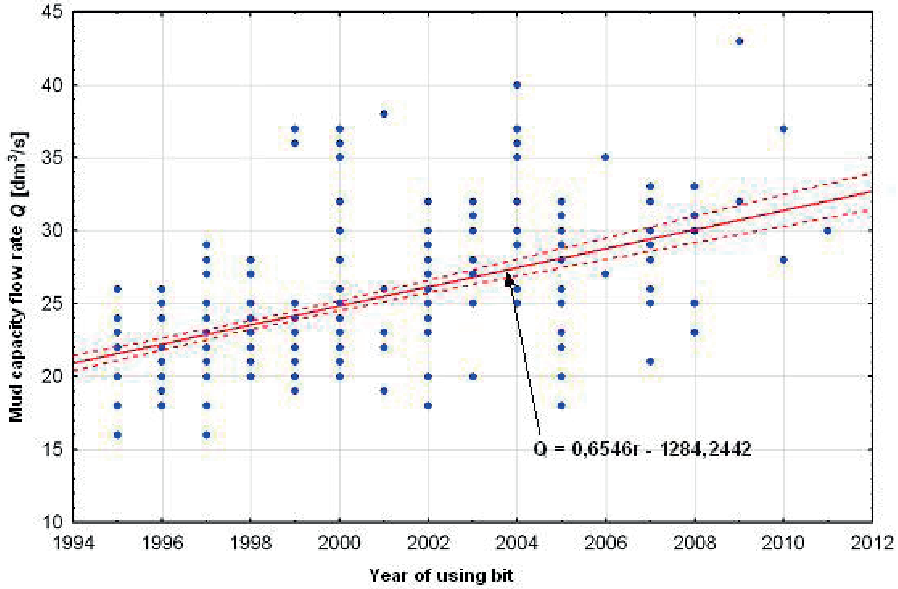

Fig. 4. Chart showing a dispersion of measure points and regression line, dependent on drilling mud capacity flow rate and year of using bits with diameter 0,216 m

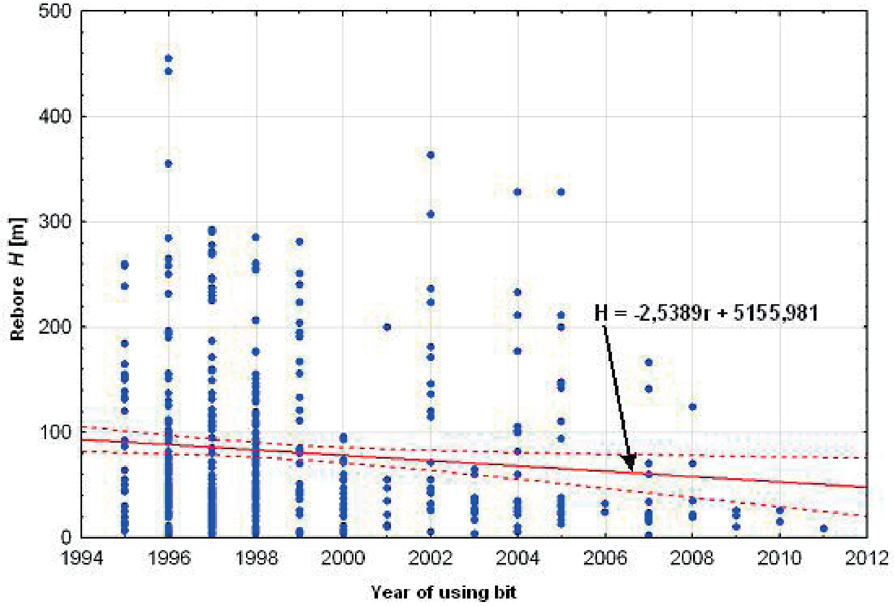

Fig. 5. Chart showing a dispersion of measure points and regression line, dependent on rebore and year of using bits with diameter 0,216 m

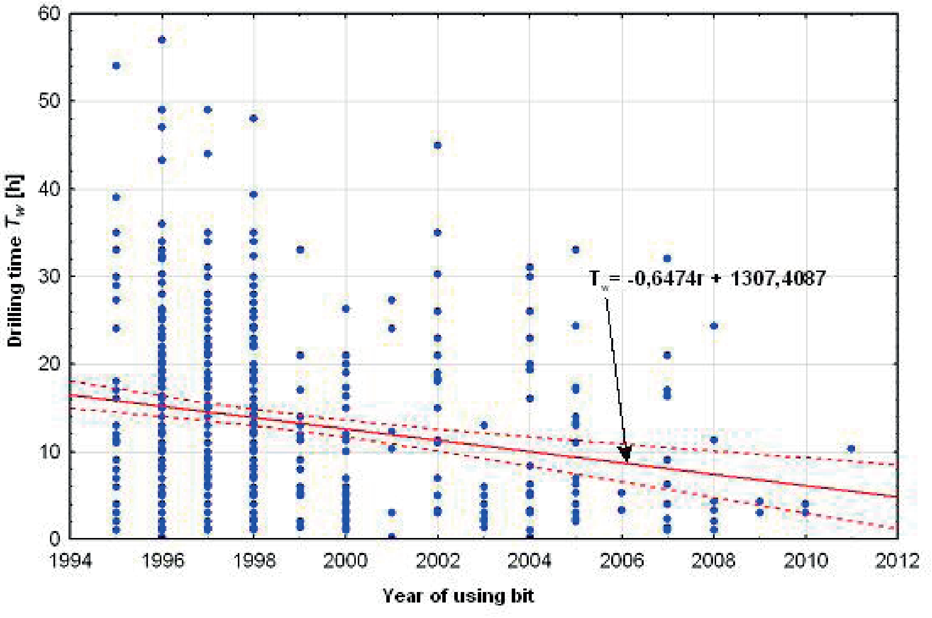

Fig. 6. Chart showing a dispersion of measure points and regression line, dependent on drilling time and year of using bits with diameter 0,216 m

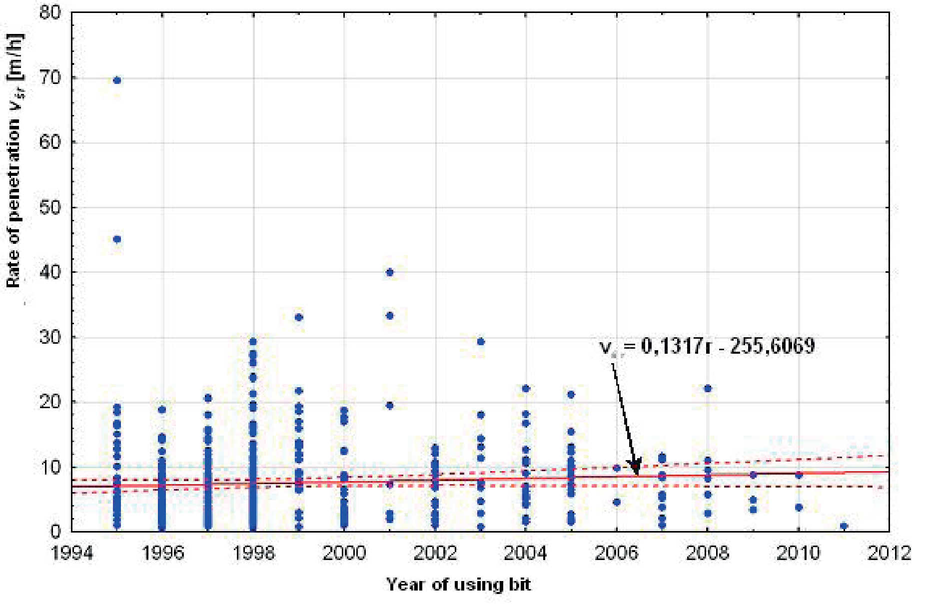

Fig. 7. Chart showing a dispersion of measure points and regression line, dependent on average rate of penetration and year of using bits with diameter 0,216 m

Table 1

Accumulation of results of the analysis of changes in technological parameters of drilling and indexes of drilling holes in a function of the year of using bits with diameter 0,216 m.

No.	Linear regression equation	Significance test of correlation factor			Significance test of linear regression factor		Number of samples n_p
		Correlation factor $\|R\|$	Critical value of correlation factor $R(\alpha,v)$	Determination factor R^2	t – Student's statistic $\|t\|$	Critical value of Statistic t – Student's $\|t\|$	
1	4	5	6	7	8	9	10
1	P = -1,984r + 4034,719	0,3376	0,090462	0,1140	7,760	1,965	470
2	$n = 0{,}5288r – 959{,}5086$	0,1362	0,090462	0,0186	2,975	1,965	470
3	$P_j{\cdot}n = -12{,}4855r + 25479{,}85$	0,2374	0,090462	0,0564	5,287	1,965	470
4	Q = 0,6546r – 1284,2442	0,5411	0,090462	0,2928	13,921	1,965	470
5	$H = -2{,}5389r + 5155{,}981$	0,1124	0,090462	0,0126	2,447	1,965	470
6	$T_w = -0{,}6474r + 1307{,}4087$	0,2129	0,090462	0,0453	4,715	1,965	470
7	$v_{śr} = 0{,}1317r – 255{,}6069$	0,0668	0,090462	0,0045	1,449	1,965	470

Analysis of the technological parameters and bit performances for diameter $D_ś$ = 0,4445 m

In the analyzed period of time of exploitation drills with diameter $D_ś$ = 0,4445 m, which were used for drilling in very soft and soft rocks on the Carpathian foreland area, it was noticed a statistically significant increase of weight on bit *P* (tab. 2, fig. 8) under stabilized values of rotational speed *n* (tab. 2, fig. 9). As the result, also a product of unit weight on bit and rotational speed $P_j{\cdot}n$ showed a growth tendency (tab. 2, fig. 10). There was also noticed an increase of drilling mud capacity flow rate *Q* (tab. 2, fig. 11).

This way of steering drilling technology parameters had enabled balancing mechanical and hydraulic powers provided to bits. The result was acquiring rebore growth tendency *H* (tab. 2, fig. 12) and drilling time T_w (tab. 2, fig. 13) under stabilized values of the average rate of penetration $v_{śr}$ (tab. 2, fig. 14).

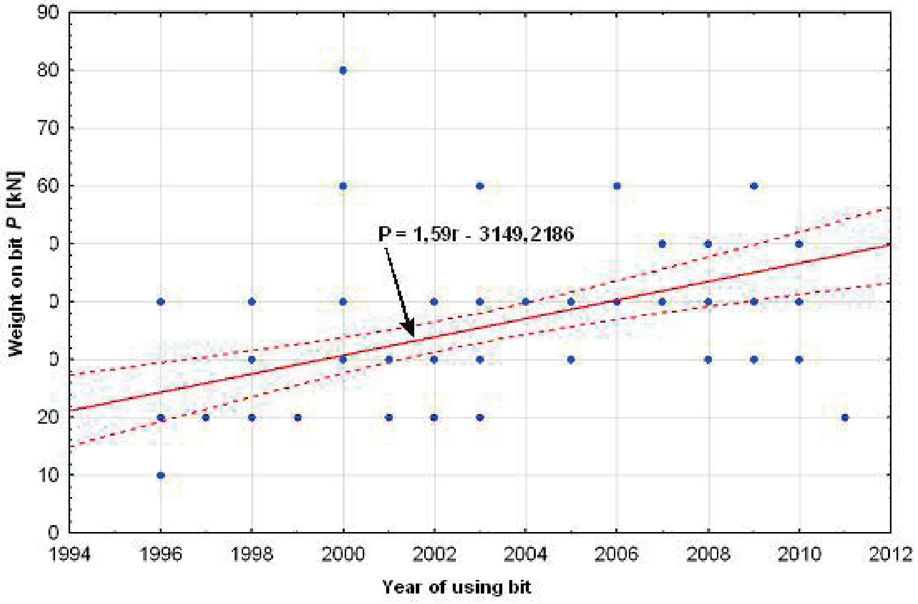

Fig. 8. Chart showing a dispersion of measure points and regression line, dependent on weight on bit and year of using bits with diameter 0,4445 m

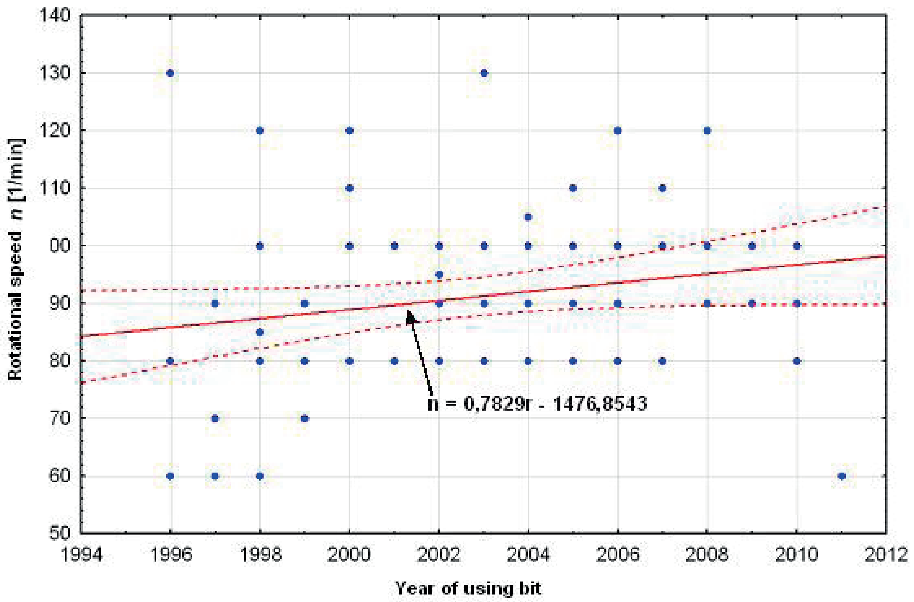

Fig. 9. Chart showing a dispersion of measure points and regression line, dependent on rotational speed and year of using bits with diameter 0,4445 m

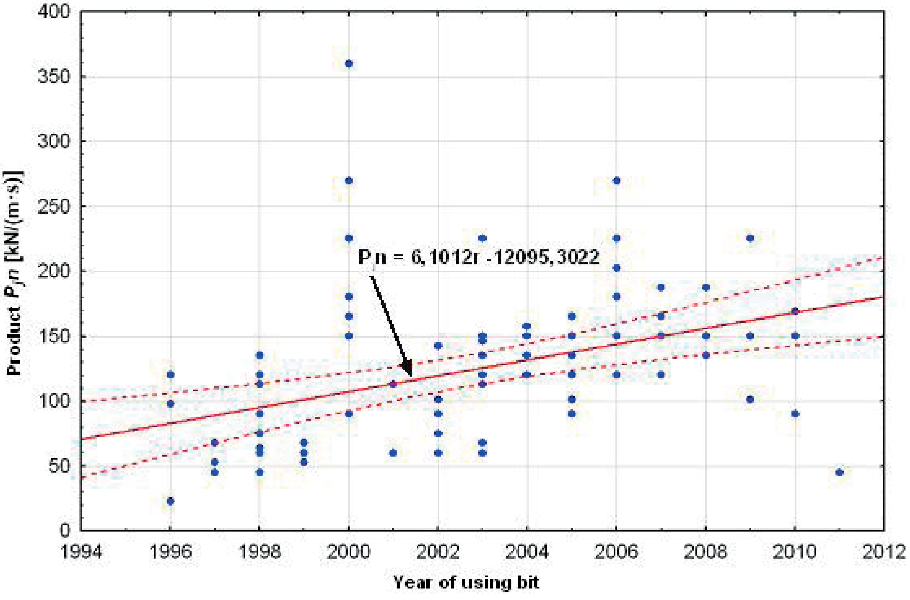

Fig. 10. Chart showing a dispersion of measure points and regression line, dependent on product of unit weight on bit and rotational speed and year of using bits with diameter 0,4445 m

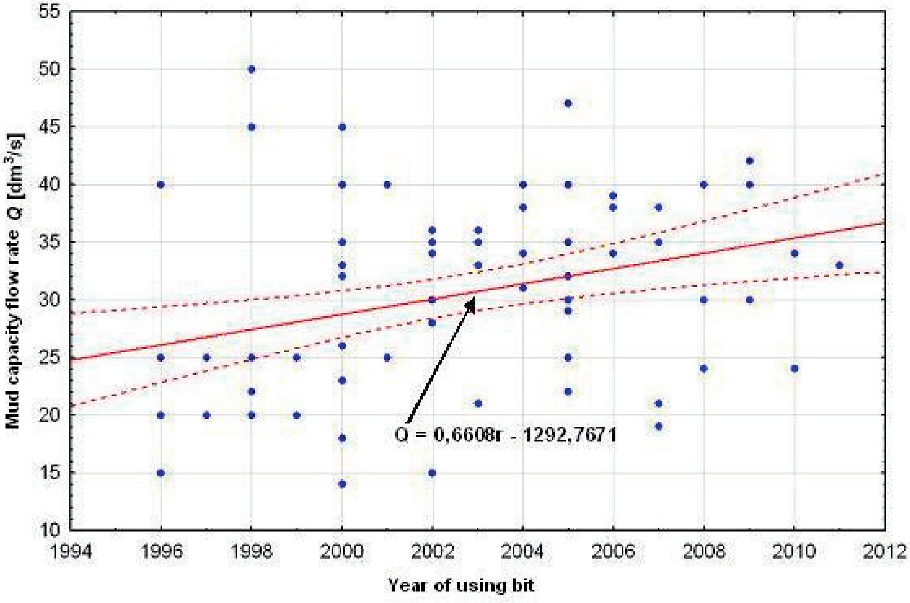

Fig. 11. Chart showing a dispersion of measure points and regression line, dependent on drilling mud capacity flow rate and year of using bits with diameter 0,4445 m

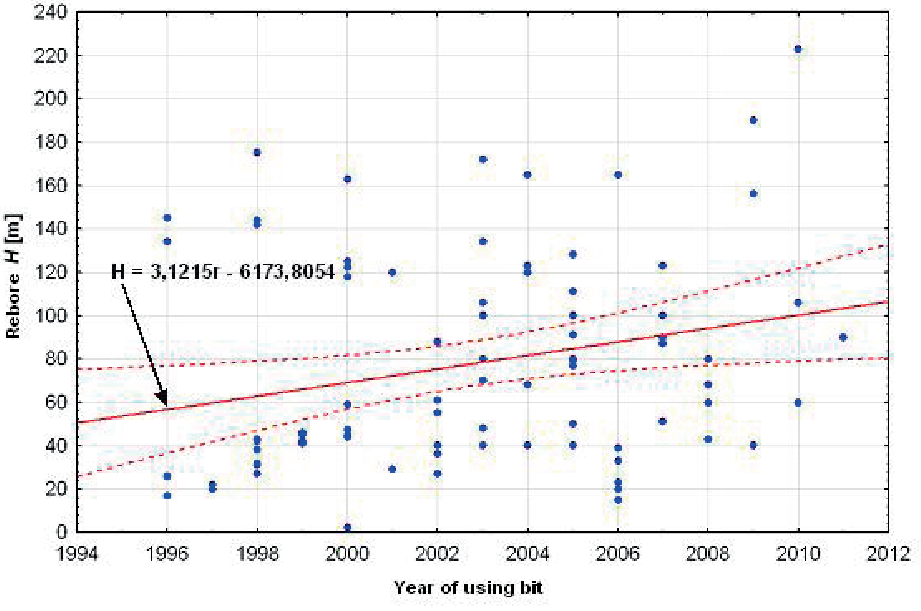

Fig. 12. Chart showing a dispersion of measure points and regression line, dependent on rebore and year of using bits with diameter 0,4445 m

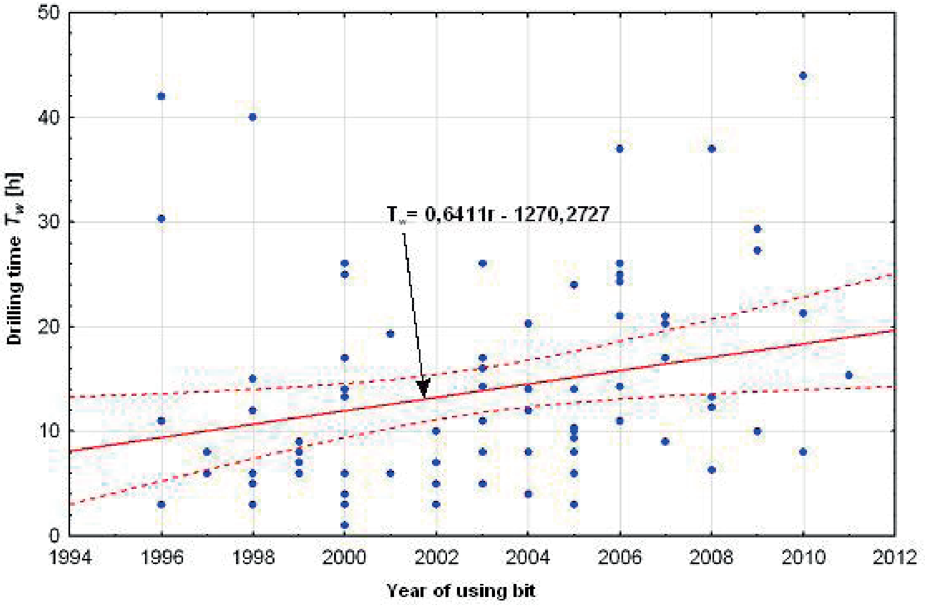

Fig. 13. Chart showing a dispersion of measure points and regression line, dependent on drilling time and year of using bits with diameter 0,4445 m

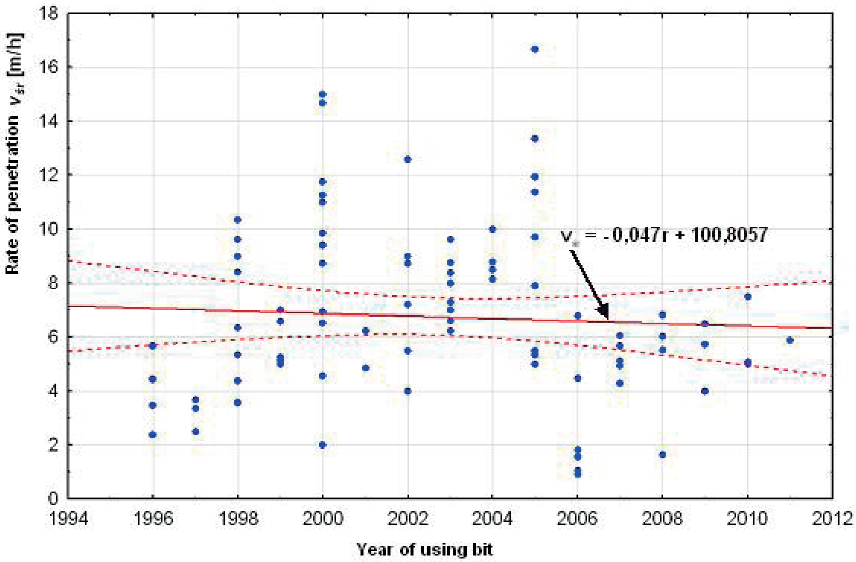

Fig. 14. Chart showing a dispersion of measure points and regression line, dependent on average rate of penetration and year of using bits with diameter 0,4445 m

Table 2

Accumulation of results of the analysis of changes in technological parameters of drilling and indexes of drilling holes in a function of the year of using bits with diameter 0,4445 m

No.	Linear regression equation	Significance test of correlation factor			Significance test of linear regression factor		Number of samples n_p
		Correlation factor $\|R\|$	Critical value of correlation factor $R(\alpha,\nu)$	Determination factor R^2	t – Student's statistic $\|t\|$	Critical value of Statistic t – Student's $\|t\|$	
1	4	5	6	7	8	9	10
1	$P = 1{,}59r – 3149{,}2186$	0,4648	0,210811	0,2160	4,840	1,988	87
2	$n = 0{,}7829r – 1476{,}8543$	0,1952	0,210811	0,0381	1,835	1,988	87
3	$P_j{\cdot}n = 6{,}1012r – 12095{,}3022$	0,3954	0,210811	0,1563	3,969	1,988	87
4	$Q = 0{,}6608r – 1292{,}7671$	0,3191	0,210811	0,1018	3,104	1,988	87
5	$H = 3{,}1215r – 6173{,}8054$	0,2503	0,210811	0,0627	2,384	1,988	87
6	$T_w = 0{,}6411r – 1270{,}2727$	0,2485	0,210811	0,0617	2,365	1,988	87
7	$v_{śr} = -0{,}047r + 100{,}8057$	0,0574	0,210811	0,0033	0,530	1,988	87

3. CONCLUSIONS

1. Statistical analyses of dependency changes of technological parameters values and holes drilling indexes on the Carpathian foreland area, that had been done with three-cone bits with bit teeth produced by "GLINIK" Company, was conducted on the sample of 776 bit runs from the years 1995 – 2011, parted and selected for four groups of bits according to their diameter and IADC code.
2. In the group of bits with diameter 0,216 m, destined for drilling in medium hard rocks and bits with diameter 0,311 m, destined for drilling in very soft and soft rocks, there was not noticed any statistically significant dependencies between values of drilling technology parameters and bit performance and time of exploiting bits. It means that in the analyzed period of time there was used stabilized technology of drilling with examined types of bits, checked in geological conditions of drilling area.
3. Drilling with bits with diameter 0,216 m in soft and very soft rocks was lead decreasing, in following years, pressure values simultaneously increasing rotational speeds and drilling mud capacity flow rate. This way of steering parameters of drilling technology may had been a result from the necessity of balancing mechanical and hydraulic powers provided to bits. Moreover, bits were put for lesser charges, what made deflection of drill string decrease. As the result, despite decreasing of the rebore values and drilling time, stable level of the average rate of penetration was reserved in the analyzed period of time.
4. Drilling with bits with diameter 0,4445 m in very soft and soft rocks was lead increasing, in following years, weights on bit and rotational speeds. The consequence was increasing the product of normalized weight on bit and rotational speed. For the purpose of balancing the increase of mechanical parameters of drilling technology, it was required to increase drilling time and rebore with the absence of statistically significant changes of the average rate of penetration.

4. DESIGNATION LIST

a – linear regression factor;
$D_ś$ – bits diameter, m;
H – bit rebore, m;
H_0 – basic hypothesis;
H_1 – alternative hypothesis;
n – bits rotational speed, min^{-1};
n_p – sample number;
p – probability of the occurrence of event;
P – weight on bit, kN;
P_j – normalized weight on bit, kN/m;
$P_j \cdot n$ – product of normalized weight on bit and rotational speed of the bit, kN/(m·s);

Q – drilling mud capacity flow rate, dm^3/s;
R – correlation factor of the sample;
R^2 – determination factor;
$R(\alpha, v)$ – critical value of the correlation factor;
r – year of bits exploitation;
T_w – drilling time, h;
t – t – Student's statistic from the sample;
$t(\alpha, v)$ – critical value of t – Student's statistic;
$v_{śr}$ – rate of penetration, m/h;
α – significance level;
v – number of latitude levels.

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