Proceedings of the 17th International Conference on Manufacturing Systems – ICMaS
ISSN 1842-3183
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Bucharest, Romania

DETERMINATION OF THE CUTTING TORQUEIN THE 4NiCr180 STAINLESS STEEL DRILLING

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Abstract: *The paper presents the methodology for determining the relationship of calculating the torque of cutting in the drilling process, in certain conditions, of a stainless steel used widely. There are presented numerous experimental data and calculations on which it analyses the torque variation of cutting. Research experiments are carried out in laboratory conditions and for representation and calculations it is used the Excel program. The methodology for determining, the experimental data and numerical, and the results of its processing represent contributions of paper to the establishment of the constant values and of the polytropic exponents for the relation calculation. The graphical representations present the variations of the cutting torque with the work parameters, which are factors for a certain recurrent relation, established in the paper.*

Key words*: cutting, process parameters, calculus methodology, regression relation, results.*

1. INTRODUCTION

The parts and assemblies made of stainless steel have an extended use in various domains such as: machinery construction, plants and equipments for the food industry, aeronautics, hydro energetic, chemicals [2, 3]. In most cases they are exposed to high wear under the action of corrosive environments and temperatures.

Processing of the stainless steel is the subject of many theoretical and experimental researches, increasingly more, of the expansion of marks and use of these materials. The parameters of processing by mechanical deformation or by cutting are determined, as well as in other steels case, by the use of its chemical, physical and mechanical characteristics.

In this aim, other papers [8], [9, 10] present many results. Also, other researches establish data to determine the choice of the cutting tools (materials, geometry, and durability) for the implementation of various technological processes [1, 7].

The parameters used for the cutting forces and torque determination, indicated by several authors [2, 5, 4, 9, 10], are: characteristics of the material processed, the cutting speed, feed, edge wear, diameter of drill, etc.

2. DATA AND EXPERIMENTAL RESULTS

The cutting conditions used for experiments were as follows:

• machine tool: boring mill in coordinates DSGS Kaunas 2431 C (Fig. 1), having the table of 480 × 420 mm, main engine power P_0 = 3.5 kW, range of cutting rotation speed D_{nc}: 10 – 3000 rev/min, range of axial feed D_{fa} : 0.02 – 0.3 mm/rev.;

• cutting tool: drills of rapid steel Rp5 (STAS 7382-88), having the hardness HRC 62, with the following values for the diameter D_t = 6, 8, 10, 12, 14 and 16 mm (STAS 573-80);

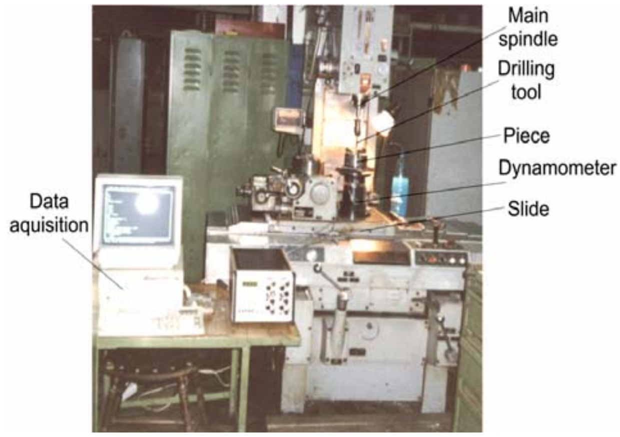

Fig. 1. Drilling machine.

• geometrical parameters of the drill type M: 2χ = 140°, the other parameters are according to STAS 1370-74, sharp type A1;

• the drills sharpening is done on the UAS-200 Cugir machine tool using an abrasive disc having the dimensions 150 × 20 × 20, in mm, E_N40M7C with a special sharpening device;

• the cooling and lubricant fluid: emulsion 20 %;

• in the machining process disc type semi-products were used.

To measure the cutting torque a dynamometer [10] was used that measured simultaneously the axial forces and cutting torque for drilling. On the circumference of the elastic sensing device four resistive transducers were attached, arranged in 90° to 90° and inclined with 45° to the generators in different directions, alternated successively. The placement and the bridge connection of the transducers led to an increase of the precision measurements of the cutting torque.

The mechanical characteristics of the stainless steels with an important role in the cutting process are: high

Table 1

Chemical characteristics

C	Ni	Cr	Mn	Si	Ti	S	P
0.041	11.7	18.3	1.9	0.4	0.4	0.15	0.035

Table 2

Mechanical characteristics

Stainless steel	**Fracture strength, R_m, N/mm^2**	**Flow limit R_{02}, N/mm^2**	**Elongation A, %**	**Hardness HB**
4NiCr180	706	515	14	186

tenacity, increased cold hardening during this process, reduced thermal conductivity compared with the non or medium allied steels [9, 10].

The main chemical and mechanical characteristics of the 4NiCr180 stainless steel are presented as follows in Tables 1 and 2 [3, 11].

In the stainless steels group, the best machining is for the steels with a rate of about 17 % Cr and low carbon content, of 0.3 – 0.4 %. A higher percent of carbon (0.8 – 1.0 %) intensifies the cutting edge wear by abrasion [10].

To study the cutting torque the well-known relation from the science literature [2, 6, 9] is considered:

$$M_c = C_M \cdot D_d^{X_M} \cdot f_a^{Y_M}, \text{ [daNmm]} \quad (1)$$

where M_c represents the cutting torque, in Nm, D_t – drill diameter, in mm, f_a – axial feed, in mm/rev, C_M – constant, and x_M and y_M – polytropic exponents.

Under this form, the relation (1) is not appropriate for the proposed analysis because it does not contain another important parameter of the cutting process, the speed.

After the experimental determinations of the cutting torque value and numerical calculation of the exponents' values and constant, these results are verified on the basis of the experimental values. Those calculations are made for the same values and working conditions. The results should not be in a large range of dispersal.

Thus, after a careful analysis of the experimental results, it has been found that the processing with different rotation speeds while keeping constant the other parameters some results with different values were obtained. These conclusions led to the modification of the structure of the relation (1) as follows:

$$M_c = C_M \cdot D_d^{X_M} \cdot f_a^{Y_M} \cdot v_c^{Z_M}, \text{ [Nm]} \quad (2)$$

where the relation between the related parameters of cutting rotation speed n_c, in rot/min and the cutting speed v_c , in m/min has been taken into account (Table 3).

To determine the values of the constant C_M and of the exponents x_M, y_M, z_M, the relation (1) was linearized by logarithmation in order to obtain:

$$\lg M_c = \lg C_M + x_M \lg D_d + y_M \lg f_a + z_M \lg v_c . \quad (3)$$

In Table 3 six sets of values for the related parameters of the cutting process state and the corresponding values of the cutting torque, indicated by the dynamometer are indicated chosen from a numerous determinations.

Table 3

Experimental data

Det. No.	**D_d** mm	**f_a** mm/rot	**n_c** rot/min	**v_c,** m/min	**M_c** Nm
1	8	0.12	560	14.07	3.77
2	8	0.20	560	14.07	5.59
3	8	0.12	900	22.61	3.27
4	12	0.12	560	21.10	7.25
5	12	0.20	900	33.91	9.24
6	10	0.12	560	17.58	5.42

By replacing in the equation (3) the data related to the first four determinations from Table 3, a linear and determined inhomogeneous system, of four equations with four unknowns is obtained in the form:

$$\begin{cases} \lg 3.77 = \lg C_M + x_M \lg 8 + y_M \lg 0.12 + z_M \lg 14.07 \\ \lg 5.49 = \lg C_M + x_M \lg 8 + y_M \lg 0.20 + z_M \lg 14.07 \\ \lg 3.27 = \lg C_M + x_M \lg 8 + y_M \lg 0.12 + z_M \lg 22.61 \\ \lg 7.25 = \lg C_M + x_M \lg 12 + y_M \lg 0.12 + z_M \lg 21.10 \end{cases} \quad (4)$$

Solving the equation system (4), the following solutions are obtained: $C_M = 0.723$, $x_M = 1.91$, $y_M = 0.72$ and $z_M = -0.30$.

Replacing these values in relation (2), the formula used to calculate the cutting torque in the considered stainless steel drilling process is obtained under the form:

$$M_c = 0.723 \cdot D_d^{1.91} \cdot f_a^{0.72} \cdot v_c^{-0.30}, \text{ [Nm]} \quad (5)$$

The values of experimental determinations 5 and 6 from Table 3 are used to verify in a numerical way the relation (5). Thus, some values of the cutting torque there were calculated beimg compared with the measured values in the experimental stage listed in the table. The data analysis shows that the calculation error is less than 2 % over the real values experimentally measured.

3. NUMERICAL APPLICATIONS AND RESULTS

Based on the relation (5), a large number of values for the cutting torque were determined according to the parameters of D_t, f_a and v_c, some of them being shown in Table 4. Also, certain graphical variations of the cutting torque were represented (Figs. 2 to 7). These graphs are valid only for the analyzed stainless steel in certain conditions. For calculations and graphical representations, the authors used the Microsoft Excel program.

Thus, in Fig. 2 the variation of $M_c = f(D_t)$ and different values of the feed f_a are presented. An exponential growth of the cutting torque with the parameter D_t results.

Knowing the torque value, it makes it possible to verify through a calculus process if the necessary cutting power is smaller than the main electric engine power.

Table 4

Cutting torque values for the drilling process of the 41NiCr180 stainless steel

v_c=28 m/min	→ *Mc(fa)* (fig.2)	**fa\Dt**	**6.00**	**8.00**	**10.00**	**12.00**	**14.00**	**16.00**
		0.1	1.55	2.69	4.12	5.84	7.84	10.11
		0.15	2.08	3.60	5.52	7.82	10.49	13.54
		0.2	2.56	4.43	6.79	9.62	12.91	16.66
		0.25	3.00	5.20	7.97	11.29	15.16	19.56
		0.3	3.43	5.93	9.09	12.88	17.28	22.30
	→ *Mc(Dt)* (fig3)	**Dt\fa**	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**
		8	1.63	2.69	3.60	4.43	5.20	5.93
		10	2.50	4.12	5.52	6.79	7.97	9.09
		12	3.54	5.84	7.82	9.62	11.29	12.88
		14	4.76	7.84	10.49	12.91	15.16	17.28
		16	6.14	10.11	13.54	16.66	19.56	22.30
D_t =12 mm.	→ *Mc(fa)* (fig.4)	**vc\fa**	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**
		18	4.05	6.66	8.92	10.98	12.89	14.70
		22	3.81	6.28	8.40	10.34	12.14	13.84
		26	3.62	5.97	7.99	9.83	11.55	13.16
		30	3.47	5.72	7.66	9.42	11.06	12.61
		34	3.34	5.51	7.37	9.07	10.65	12.15
	→ *Mc(vc)* (fig.5)	**fa\vc**	**16.00**	**20.00**	**24.00**	**28.00**	**32.00**	**36.00**
		0.1	6.90	6.46	6.11	5.84	5.61	5.41
		0.15	9.25	8.65	8.19	7.82	7.51	7.25
		0.2	11.37	10.64	10.07	9.62	9.24	8.92
		0.25	13.36	12.49	11.83	11.29	10.85	10.47
		0.3	15.23	14.24	13.48	12.88	12.37	11.94
f_a = 0.1 mm/rev	→ *Mc(Dt)* (fig6)	**vc\Dt**	**6.00**	**8.00**	**10.00**	**12.00**	**14.00**	**16.00**
		18	1.77	3.07	4.70	6.66	8.95	11.55
		22	1.67	2.89	4.43	6.28	8.42	10.87
		26	1.59	2.75	4.21	5.97	8.01	10.34
		30	1.52	2.64	4.04	5.72	7.68	9.91
		34	1.47	2.54	3.89	5.51	7.39	9.54
	→ *Mc(vc)* (fig.7)	**Dt \vc**	**12.00**	**16.00**	**24.00**	**28.00**	**32.00**	**36.00**
		6	2.00	1.84	1.63	1.55	1.49	1.44
		8	3.47	3.18	2.82	2.69	2.59	2.50
		10	5.31	4.87	4.32	4.12	3.96	3.82
		12	7.53	6.90	6.11	5.84	5.61	5.41
		14	10.10	9.27	8.21	7.84	7.53	7.27

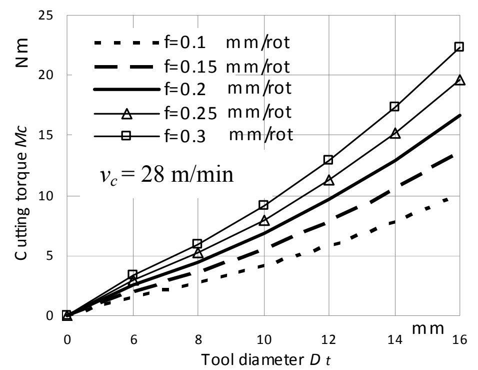

Fig. 2. Cutting torque variation with parameters D_t and f_a.

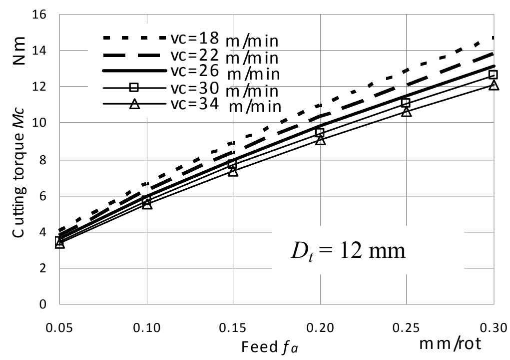

Fig. 4. Cutting torque variation with parameters f_a and v_c.

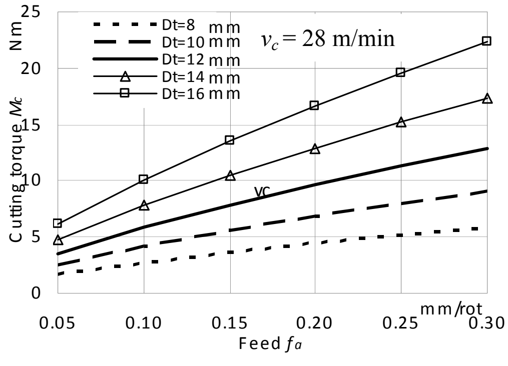

Fig. 3. Cutting torque variation with parameters f_a and D_t.

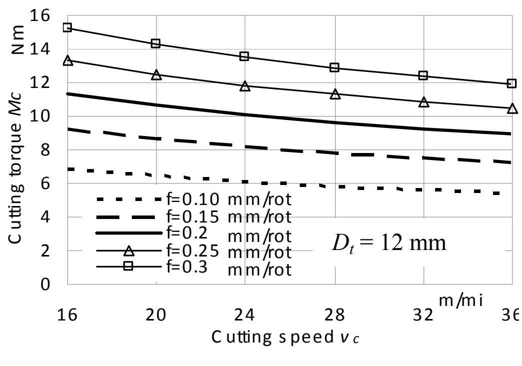

Fig. 5. Cutting torque variation with parameters v_c and f_a.

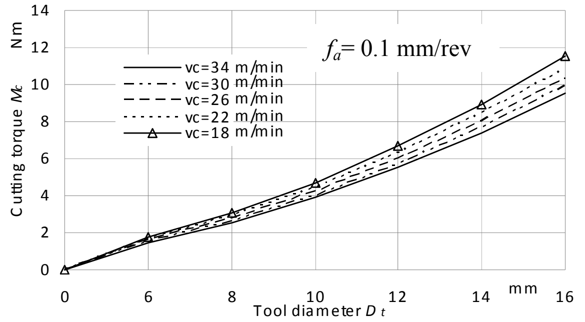

Fig. 6. Cutting torque variation with parameters D_t and v_c.

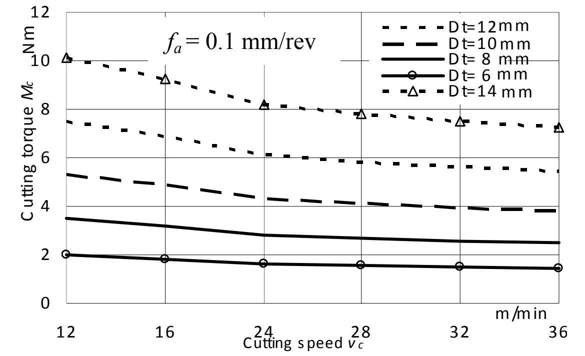

Fig. 7. Cutting torque variation with parameters v_c and D_t.

Both the data inscribed in Table 4 and the graphical representations from Figs. 2 to 7 respect the regression function (5). From the study of the polytropic exponents in this function previously determined, the following affirmations results:

• for the same values of the parameter D_t, the cutting torque M_c results with higher values with the growing variation of the feed f_a;

• for the same values of the axial feed, the cutting torque M_c has greater values with the growing of the parameter D_t than of the feed;

• there is an exponential decrease of the torque during the increase of the cutting speed (Figs. 5 and 7).

4. CONCLUSIONS

From the analysis of the obtained results the following important conclusions can be drawn:

• for the established variation range of parameters M_c, D_t and v_c (see Tabel 4) of the cutting torque, values between 1.5 and 22.3 Nm result. The dynamometer allows to measure torque values located in the range M_c: 0.45 ... 300 Nm. The limitations of the parameter range are determined by the power of the main electric engine of the drilling machine;

• by many experimental determinations and result verifications it was demonstrated the necessity of modifying the structure of the calculus relation of the cutting torque from the science literature in the terms of considering the cutting speed as a parameter, as a result of relations (2) and (5) respectively.

• the analysis of graphs shows the exponential increase of the torques with the feed f_a increase and also with the drill diameter increase. On the other hand, it is reveiled the decreases of the exponential cutting torques (*Mc*) with the increase of the cutting speed.

• the practical results presented in this paper may could be added to the numerous existing researches in the domain of processing by cutting the stainless steels. Also, the results could be used directly in activities of the technological design and production.

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