New Mathematical Models of Axial Cutting Force and Torque in Drilling 20MoCr130 Stainless Steel

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Abstract: - Stainless steels represent materials which have known a continuous extend into various and interesting industrial fields application. Most of the time they needs machining and, one important procedure is drilling. The paper present aspects of the experimental research developed in the purpose of determining new and, more adequate, mathematical models of the cutting force and torque, in drilling 20MoCr130 stainless steel. Graphs, as well as further application of the obtained relationships are also, mentioned.

Key-Words: - axial cutting force, torque, drilling, stainless steel, mathematical model

1 Introduction

There are, almost, 100 years since stainless steels have been “discovered” and, nowadays, their application fields are various and challenging. That is because of their important physical and mechanical characteristics, most of all, their high corrosion resistance to various chemical agents and, why not, because of their impressive good look [2].

Usually, after obtaining, as rough material, machining is necessary, so as to obtain the shape, dimensions and surface roughness of the stainless steel part. These steels are very tough, with low thermal conductivity and, while machining, determines sever wear of the cutting tool, as well as, high value cutting forces [6].

Because of their high prices, researches on their machinability are necessary, in order to optimize the machining process, meaning, having high productivity and low costs of stainless steel parts. One important aspect of material’s machinability is represented by the values of the cutting force and torque, meaning the higher the values, the lower machinability is so, resulting a low energy efficiency use [3]. Specific literature presents some relationships regarding variables of the machining process – involving force and torque but, when experimentally checking them, one can notice, relative high difference (of the modeled ones) from the real obtained values [5]. So, it has been considered useful to determine adequate models of some machining process parameters, regarding one widely used Romanian stainless steel – 20MoCr130.

Obtaining holes, in stainless steel parts, of various dimensions and precisions, is done by drilling.

Cutting force, specially axial one, and cutting torque, are important parameters (output variables) of the drilling process and, can be often used for its optimization.

Based on the above, this paper presents the experimental steps carried out in order to determine some mathematical models of axial cutting and torque in drilling 20MoCr130 stainless steel.

2 Research Methodology

In order to experimentally determine a mathematical relationship of variables specific to a machining process, there has to be mentioned, both the independent and the dependent ones [1]. After doing that, the dependence relation type must be settled and, correspondingly, the appropriate experiments design established.

The mathematical relations, regarding axial cutting force, in drilling stainless steel materials, presented by most of the articles and books dealing with this problem, are of the type:

$$F = C_F D^{x_F} a_f^{y_F} \quad [\text{N}] \qquad (1)$$

$$M = C_M D^{x_M} a_f^{y_M} \quad [\text{Nm}] \qquad (2)$$

where: F is the axial component of the cutting force;
M – the drilling torque;
D – the diameter of the drilling tool, [mm];
a_f – cutting feed, of the drilling tool, [mm/rot];
x_F , y_F , x_M , y_M - polytropic exponents;
C_F , C_M - constants.

If experiments were carried out, once the values of C_F, C_M, x_F, y_F, x_M, y_M known, for the same values of cutting tool's diameter and cutting feed but, for different values of cutting speed, different axial force and torque values were obtained. So, one could think that the parameter not mentioned by relations (1) and (2), meaning cutting speed, should play an important role in drilling axial force and torque prediction.

As consequence of the above mentioned, this paper presents another mathematical relationship of the axial cutting force and, respectively, of the torque, where one more independent variable appear, meaning the *cutting speed v* [mm/rot]. So, the new, original proposed mathematical models are:

$$F = C_F D^{x_F} a_f^{y_F} v^{z_v} \quad [\mathrm{N}] \qquad (3)$$

$$M = C_M D^{x_M} a_f^{y_M} v^{z_M} \quad [\mathrm{Nm}] \qquad (4)$$

where: v is peripheral rotational speed of the drilling tool, usually mentioned as cutting speed [m/min];

z_v, z_M - polytropic exponents;

For obtaining the constants and polytropic exponents' values, relations (3) and (4) must be of linear type and, so, by logarithm their linear expressions are:

$$\lg F = \lg C_F + x_F \lg D + y_F \lg a_f + z_F \lg v \qquad (5)$$

$$\lg M = \lg C_M + x_M \lg D + y_M \lg a_f + z_M \lg v \qquad (6)$$

3 Mathematical Models

Obtaining final formula of the new mathematical models implies, first, experiments and, after that, constants and polytropic exponents determination.

3.1 Experiments

There were carried out experiments under specially designed conditions.

So, the machine tool was a drilling machine, coded GC_032DM_3. whose electric motor had 3,5 kW power. The working table dimensions were 420 × 480 (mm) and the main spindle had a no. 4 Morse cone. Possible rotational speed range values of the drilling tool were 70 ÷ 1400 [rot/min], with 12 geometrical ratio levels variation and possible cutting feed values were 0.12; 0.20; 0.32; 0.50 [mm/rot].

There has been used a cooling/lubricating fluid, 20% P emulsion.

Cutting tools were helix drilling ones, made of Rp5 material and having Rockwell hardness no. 62. The edge angle was $2\chi = 140^\circ$ and the diameter' values considered were:

$$\Phi_1 = 8; \quad \Phi_2 = 12; \quad \Phi_3 = 14 \quad [\mathrm{mm}]$$

As for the drilling experimental conditions, they were according to R1370/2-69 Standard, type A.

For adequate measuring of axial cutting forces and torques, in drilling, there has been deigned and manufactured a special rotational device. Its most important element is represented by the elastic sleeve, on which there were attached four resistive transducers, each inclined by 45° with respect to horizontal and vertical axes.

The "exit" cables of this device were connected to an IEMI type electronic bridge which, was coupled to a data acquisition system, using the graphical programming LabVIEW software. – see Figure 1.

The studied material was 20MoCr130, its chemical structure being presented in Table 1, while its mechanical characteristics are mentioned by Table 2

Table 1 Chemical Structure.

C [%]	Mo [%]	Ni [%]	Cr [%]	Mn [%]
0.20	3.82	0.24	13.2	0.68
Si [%]	S [%]	P [%]		
0.30	0.017	0.035		

Table 2 Mechanical Characteristics.

Tensile Strength, R_m [N/mm^2]	Flow Strength, R_{02} [N/mm^2]	Relative Elongation δ [%]	Hardness, HB
920	670	10.7	240

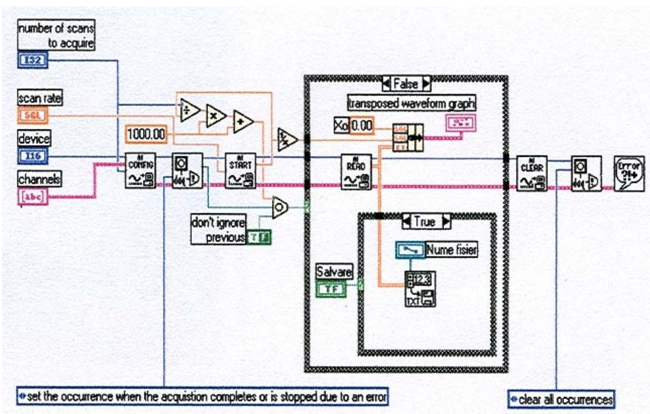


Fig.1 LabVIEW graphical program

Images of the designed stand, taken while experimenting are shown in figure 2.

An example of the obtained graphic, for all drilling force's components, as well as for the power involved by the process is presented in Figure 3.

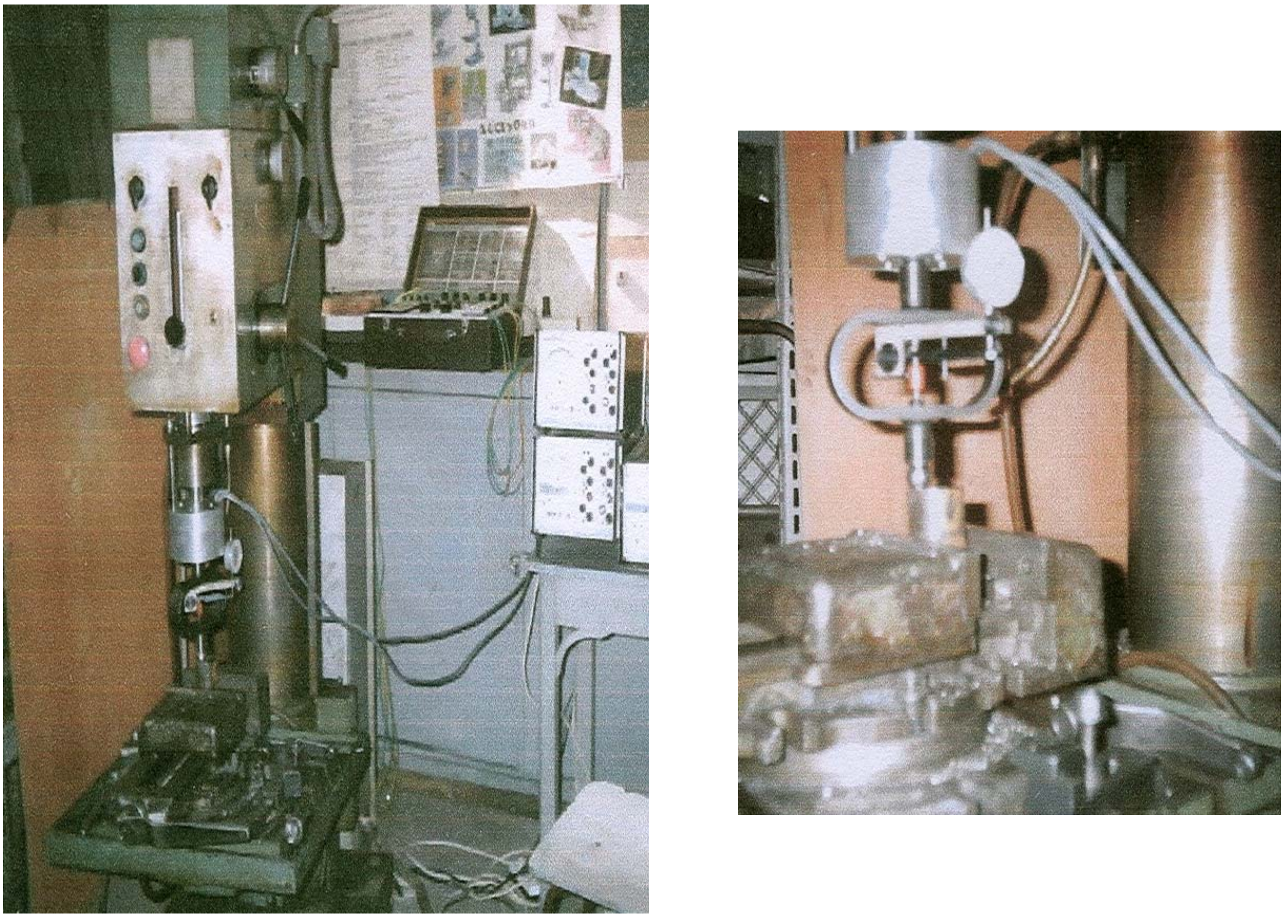


Fig.2 Experimental stand

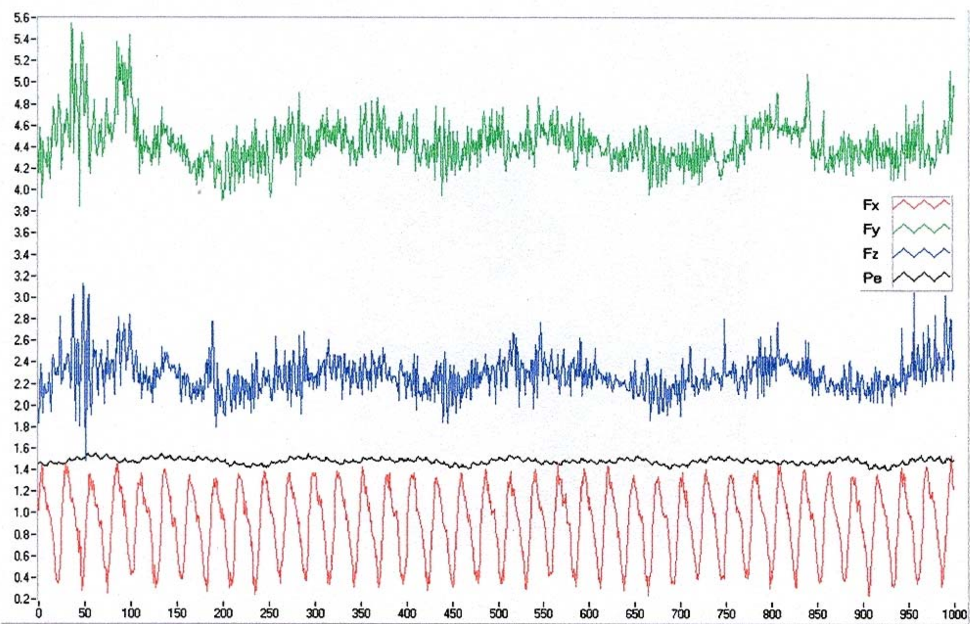


Fig.3 LabVIEW data acquisition – drilling force's components graphics

Table 3 Experimental results

Exp. No.	Cutting Tool Diameter, D [mm]	Cutting Feed a_f [mm/rot]	Rotational Speed n [rot/min]	Cutting Speed v [m/min]	Axial Cutting Force, F [N]	Drilling Torque M [Nm]
1	8	0.12	560	14.07	2282	4.97
2	8	0.20	560	14.07	2976	6.68
3	8	0.12	900	22.61	1998	4.43
4	12	0.12	560	21.10	3522	9.54
5	12	0.20	560	21.10	4502	12.58
6	14	0.12	900	39.56	3565	10.71

where: n is the rotational speed of the machine tool's main spindle

$$n = \frac{1000v}{\pi D} \quad \text{[rot/min]}$$

Experimental values obtained for the axial force and torque, in drilling 20MoCr130 stainless steel are shown in Table 3.

2.2 Obtaining Mathematical Models

Based on the experimental results, and on research methodology mentioned, the equation systems necessary for models' determination are as follows:

$$\begin{cases} \lg 2282 = \lg C_F + x_F \lg 8 + y_F \lg 0.12 + z_v \lg 14.07 \\ \lg 2976 = \lg C_F + x_F \lg 8 + y_F \lg 0.20 + z_v \lg 14.07 \\ \lg 1998 = \lg C_F + x_F \lg 8 + y_F \lg 0.12 + z_v \lg 22.61 \\ \lg 3522 = \lg C_F + x_F \lg 12 + y_F \lg 0.12 + z_v \lg 21.10 \end{cases} \quad (7)$$

$$\begin{cases} \lg 4.97 = \lg C_M + x_M \lg 8 + y_M \lg 0.12 + z_M \lg 14.07 \\ \lg 6.68 = \lg C_M + x_M \lg 8 + y_M \lg 0.20 + z_M \lg 14.07 \\ \lg 4.43 = \lg C_M + x_M \lg 8 + y_M \lg 0.12 + z_M \lg 22.61 \\ \lg 9.54 = \lg C_M + x_M \lg 12 + y_M \lg 0.12 + z_M \lg 21.10 \end{cases} \quad (8)$$

By solving the equations systems, the values of constants, C_F, C_M and polytropic exponents, x_F, y_F, x_M, y_M are obtained [5].

Knowing that the initial dependence relationships were exponential ones, and the ones used in solving are obtained from the first ones, by logarithm, the final mathematical models of the axial cutting force and torque, in drilling 20MoCr130 stainless steel are:

$$F = 870 D^{1.35} a_f^{0,52} v^{-0.28} \quad \text{[N]} \qquad (9)$$

$$M = 0.684 D^{1.85} a_f^{0,58} v^{-0.24} \quad \text{[Nm]} \qquad (10)$$

Graphs of the axial force and torque variances, on some of the considered variables are shown in Figure 4 and, respectively, Figure 5.

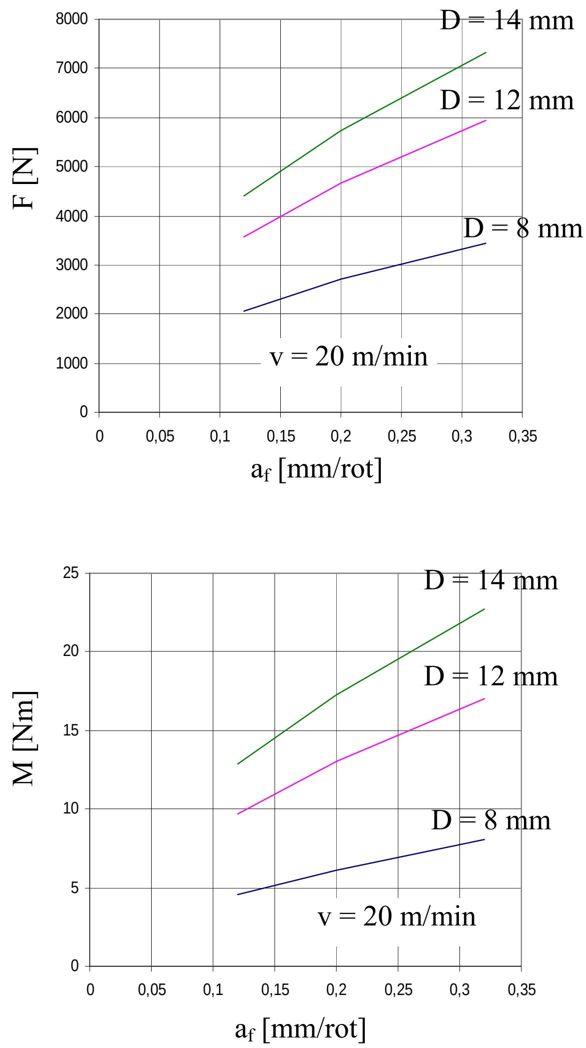


Fig.4 Axial force, F, and torque variation, M, on cutting feed, a_f

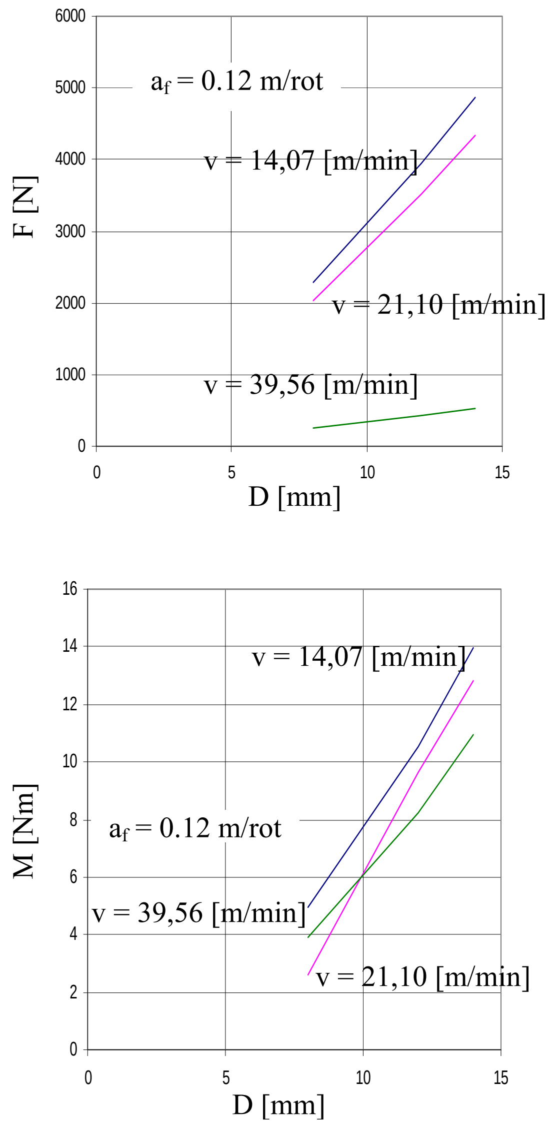


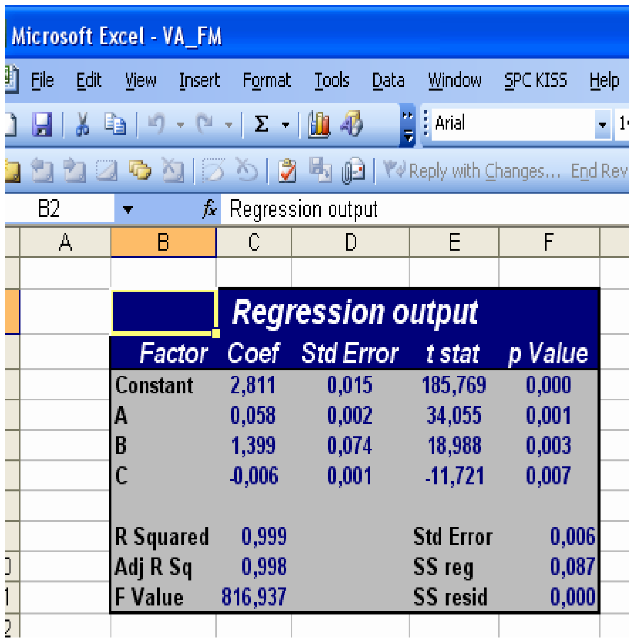
Fig.5 Axial force, F, and torque variation, M, on cutting tool diameter, D

As relations (9) and (10) were obtained by solving classical equation systems – four unknown parameters and four equations, one can think of trying to improve the obtained mathematical models. That is if, changing one of the equations – in systems (7) and, respectively, (8), by considering another experimental results from Table 3 – experiment number 5 or, 6, different values for the constants and polytropic exponents should be obtained.

So, considering all the values from Table 3, and using a specialized software – SPC KISS, regression analysis has been carried out [4].

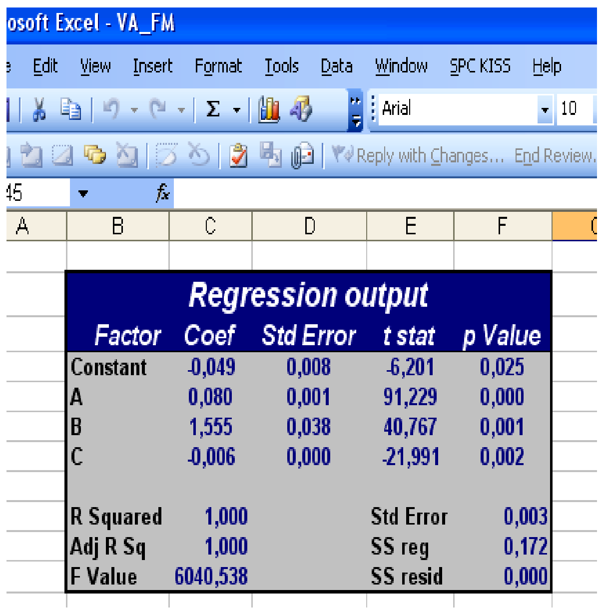
Figures 6 and 7 show the obtained results – meaning constants and coefficients' values, standard errors of the coefficients, standard error, R^2 coefficient (determination coefficient), values of t and F tests, etc.

Based on this regression analysis, the mathematical models for the axial component of e drilling force, F and for the drilling torque, M are as shown by relations (11) and (12):



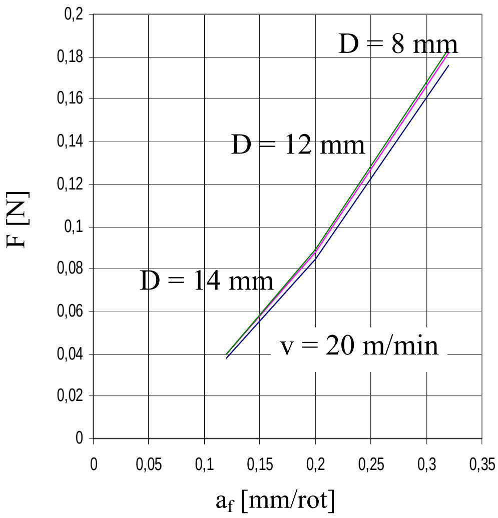
Regression output				
Factor	Coef	Std Error	t stat	p Value
Constant	2,811	0,015	185,769	0,000
A	0,058	0,002	34,055	0,001
B	1,399	0,074	18,988	0,003
C	-0,006	0,001	-11,721	0,007
R Squared	0,999		Std Error	0,006
Adj R Sq	0,998		SS reg	0,087
F Value	816,937		SS resid	0,000

Fig.6 SPC KISS regression analysis – for axial force, F model



Regression output				
Factor	Coef	Std Error	t stat	p Value
Constant	-0,049	0,008	-6,201	0,025
A	0,080	0,001	91,229	0,000
B	1,555	0,038	40,767	0,001
C	-0,006	0,000	-21,991	0,002
R Squared	1,000		Std Error	0,003
Adj R Sq	1,000		SS reg	0,172
F Value	6040,538		SS resid	0,000

Fig.7 SPC KISS regression analysis – for torque, M model



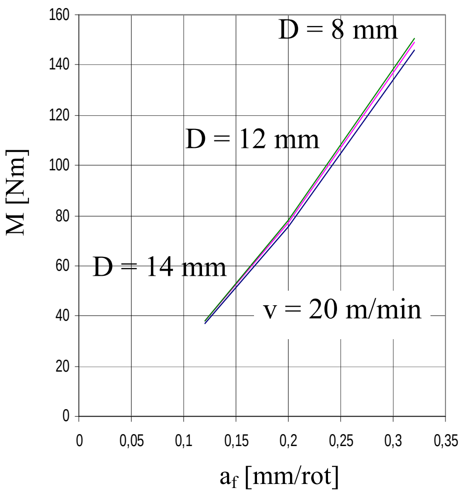


Fig.8 Axial force, F, and torque variation, M, on cutting feed, a_f

$$F = 648 D^{0.058} a_f^{1.399} v^{-0.006} \quad [\text{N}] \qquad (11)$$

$$M = 0.893 D^{0.080} a_f^{1.555} v^{-0.006} \quad [\text{Nm}] \qquad (12)$$

Graphs of the axial force and torque variances, are shown in Figure 8 .

4 Conclusion

Analyzing the mathematical models obtained, can be noticed that *the ones obtained by SPC KISS software do not fit the experimentally obtained results*.

Even the regression analysis proved to be adequate, for real, when checking with the observations resulting from experiments, high differences occurred. Perhaps the data, were not enough or, not adequately established for the implied regression software. So, there will be *considered right*, only the mathematical models given by relation (9) – for axial drilling force and, by relation (10) – for drilling torque.

From these models, one can notice that the higher influence on the dependent variable (F, or M) is that of cutting tool diameter, D, meaning, the larger the drilled hole, the higher the force and moments values. It can, also, be noticed out of the variation graphs plotted in Figure 5. The lower influence, on the same studied dependent variables is that of the cutting speed, v, but, it is a reveres influence – the higher values of v, the lower values of F and M.

Both mathematical models, for axial drilling force and drilling torque, are, somewhat, correlated, meaning it resulted the same, similar, influences of the independent variables studied (D, s, v).

Once determined, the considered models were further checked, by more experiments – for different values of the parameters. All the experimentally obtained results were in good concordance with the mathematically predicted values.

Further research should be developed so as, to implement the obtained results – mathematical models, into an automated optimization system .of the manufacturing process.

References:

[1] Iliescu M., Vlădăreanu L, "Statistic Models of Surface Roughness MET 4 Metallized Coating in Grinding Manufacturing System", 12th *WSEAS International Conference on Systems*, pag. 777-782, ISSN 1790-2769, Greece, July, 2008

[2] Grigoriu M, Gheorghiu L., *Energy Efficiency Pumping Systems Improvement Method*, Energetica Journal, no. 2/2008, pag. 74-78, ISSN 1453-2360, Bucharest, 2008

[2] Dumitrescu C. I., , Grigoriu M, National *Energy Market Highliths*, Energetica Journal, no. 4/2008, pag. 109-113, ISSN 1453-2360, Bucharest, 2008

[3] Montgomery D, Runger G, *Applied Statistics and Probability for Engineers*, John Wiley & Sons, Inc., 2003

[4] Ghionea A., Vlase A, Ghionea I, Wear Evaluation of Cutting Edge and Cutting Speed in Drilling Process of Some Manganese Steel, Proceedings of 18th International DAAAM Symposium ISSN 1726-9679, Austria, 2007

[5] Vlase I, Contribution to Determining of Some Indexes for Quantifying the Stainless Refractory Steels Machinability, Doctoral Thesis, 2002.