Processing Transducers' Signals when Determining Mathematical Models of Force and Torque in Drilling 2MoNiCr175 Steel

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Abstract: - Whenever experimental research involves some devices for measuring certain characteristics, there are used special elements, such as transducers, and high importance has to be given when processing their "exit" signals. This article points out the importance of resistive transducers' signals processing when new mathematical models of axial force and torque are determined, in drilling 2MoNiCr175 stainless steel.
Key-Words: - axial cutting force, torque, drilling, stainless steel, mathematical model

1 Introduction

Stainless steels have been used for the last 100 years because of their performances – specially, when mechanical resistance, high temperature stability and good various chemical agents corrosion protection are need. Another reason, for their extensive use is their aspect – always shining, not scratched and good looking [4].

Nowadays research is directed toward stainless steels constitutive elements, as to get better performances in quality and machinability but, anyway, economical efficiency is always on target.

Once obtained, many times, stainless steels parts need machining, such as turning, drilling, milling, etc. Machining these materials is difficult because of some facts, such as: material is hardening while cutting chip is forming; low thermal conductivity and, thus, temperature into the cutting zone "gets" high; intensive cutting tool wear is going on; relevant values of cutting forces can be observed.

As mentioned above, and as presented by specific literature, there are a lot of factors involved in appreciating one material's machinability (cutting tool wear, optimum cutting speed value, surface roughness, etc.), among which, an important one being the values of cutting force and/or cutting torque. Research has been done so as to get minimum of their values, while cutting [2].

In order to measure forces and moments [4], [5], while machining, there have to be used special devices, equipped with elements sensitive to loading, meaning, with *transducers* – resistive, inductive, capacitive, etc., ones. A correct "translation" of their "exit signals" into real force / torque values involves appropriate signal processing.

There are many cases when stainless steel parts' configuration involves wholes – small or, large in diameter. A high percentage of these are obtained by drilling so, determining real values of cutting force (mainly, its axial component), as well as of cutting torque represent important step in studying material's machinability.

This paper points out how signals processing was carried on, so as to get fitted mathematical models of axial cutting force and torque, in drilling 2MoNiCr175 stainless steel – a material widely used in real life applications.

2 Research Methodology

When experimentally determining mathematical relationship of a machining process specific variables, it has to be mentioned which of them are the independent and which are the dependent ones [1]. Then, the appropriate design of experiments must be considered and, finally, the corresponding regression models should be determined.

The mathematical relations of axial cutting force and torque in drilling stainless steel materials, presented by most of the articles and books dealing with this problem [4], are as:

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

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

where: F is the axial component of the cutting force;
M – drilling torque;
D – drilling tool diameter, [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.

Once the values of C_F, C_M, x_F, y_F, x_M, y_M settled, when further experimenting, there has been noticed that same values of cutting tool's diameter, D, and cutting feed, a_f, but, various cutting speed values, v, involve different axial force and torque values [3]. So, it should be supposed that the parameter not mentioned by relations (1) and (2), meaning cutting speed, should play an important role in prediction of drilling axial force and torque values.

Thus, another mathematical relationship of the axial cutting force and, respectively, of the torque, is recommended, where one more independent variable appear, meaning the *cutting speed v* [mm/rot]. So, the new, original proposed mathematical models are:

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

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

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 linear ones, so, by logarithm they turn into linear equations system:

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

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

3 Experiments

Experiments were carried out under specially designed conditions, most important of them being stated below.

♦ Drilling machine tool was the one coded with $GC_0 32DM_3$, its electric motor being of 3,5 kW power. Machine plateau dimensions were 420 × 480 (mm) and the main spindle had a no. 4 Morse cone. Rotational speed range values of the main spindle were 70 ÷ 1400 [rot/min], with 12 geometrical ratio levels variation and possible cutting feed values of 0.12; 0.20; 0.32; 0.50 [mm/rot].

♦ While drilling, there has been used a cooling / lubricating fluid, 20% P emulsion.

♦ Cutting tools were helix drilling ones, made of Rp5 material, with Rockwell hardness, HRC 62. Edge angle was $2\chi = 140^\circ$ and the diameter' values considered were of 8 and 12 mm.

Table 1 Chemical Structure.

C [%]	Mo [%]	Ni [%]	Cr [%]	Mn [%]
0.021	4.30	12.60	17.60	1.70
Si [%]	Ti [%]	S [%]	P [%]	
0.56	0.37	0.02	0.03	

Table 2 Mechanical Characteristics.

Tensile Strength, R_m [N/mm^2]	Flow Strength, R_{02} [N/mm^2]	Relative Elongation δ [%]	Hardness, HB
661	482	15	174

♦ Experimental conditions were according to R1370/2-69 Standard, type A.

♦ Material was 20MoCr130, its chemical structure and mechanical characteristics being presented in Table 1 and, respectively, in Table 2

♦ Measuring axial cutting forces and torques, in drilling, was possible due to the fact that there has been deigned and manufactured a special rotational device – see figure 1.

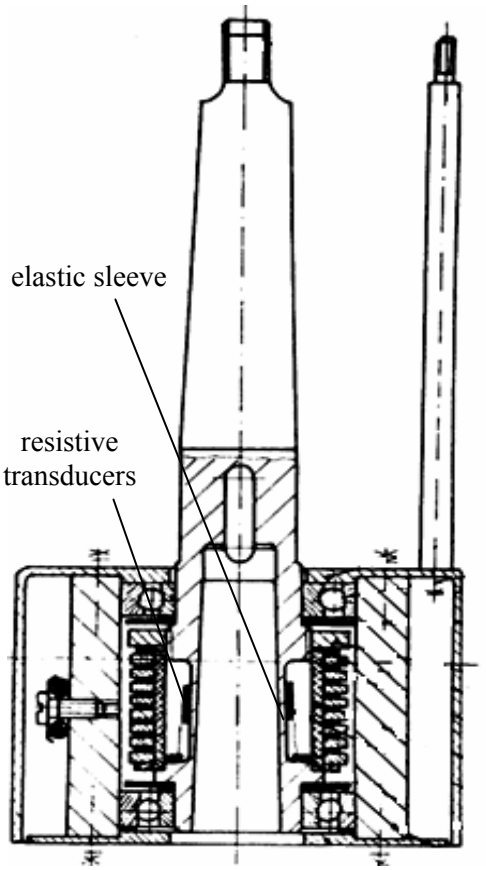

Fig.1 Schematic representation of the device for measuring axial force and torque, in drilling

It should be mentioned that device's most important element is the elastic sleeve, on which there are attached four resistive transducers, each inclined by 45° with respect to horizontal and vertical axes.

The transducers type was, as follows:

- for axial force measuring - KM120, of 120 Ω resistance and 2.07 constant, half bridge connected, R2/4;
- for torque measuring - SM120, of 120 Ω resistance and 1.91 constant, complete bridge connected, R2/4.

♦ "Exit" cables of the device were connected to a IEMI type electronic bridge (N2300.14), succeeded by an amplifier (N2314) and data printing unit (N2322).

♦ Better and more precisely experimental results were obtained by using a data acquisition system (AT-MIO-16L-9) with ± 10 V measuring interval and 12 bits resolution. Its measuring precision was calculated by relation (7):

$$precision = \frac{\text{amplitutde of measuring field}}{2^{\text{resolution}}} = \frac{20}{2^{12}} = 4{,}88\ mV \quad (7)$$

♦ LabVIEW graphical programming software enabled complete and accurate processing of a large number of experimental data, it's customized scheme being presented in figure 2.

An image of the experimental stand is shown by figure 3, while the drilling force's components value and variation can be noticed in a "computer screen" print – see figure 4.

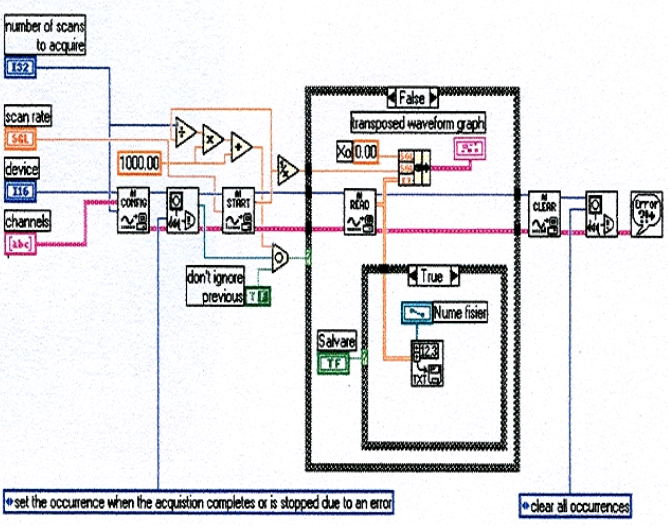

Fig.2 LabVIEW graphical program

Fig.3 Experimental stand

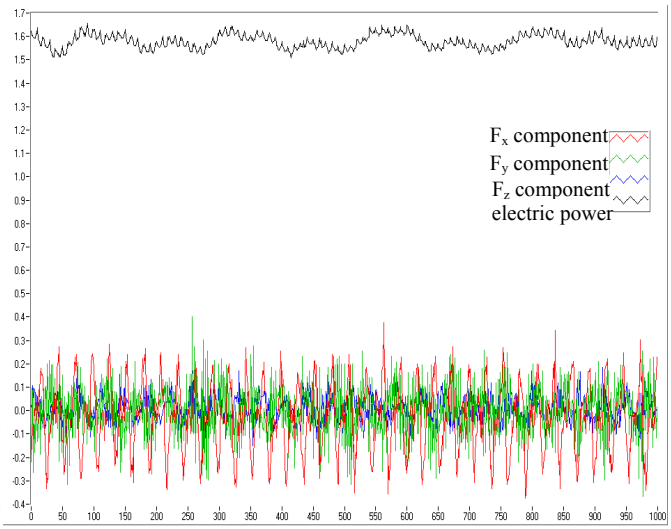

Fig.4 LabVIEW data acquisition – drilling force's components graphics

Before experimenting, all the system (device, data acquisition, LabVIEW program) has been calibrated. So, experimental values obtained for the axial force and torque, in drilling 2MoNiCr175 stainless steel are shown in Table 3.

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 Force and Torque Exit Channels Values		Real Axial Force and Torque Values	
					F [V]	M [V]	F [N]	M [Nm]
1	8	0.12	560	14.07	12.71	0.964	1652	3.60
2	8	0.20	560	14.07	16.82	1.336	2187	4.99
3	8	0.12	900	22.61	10.61	0.849	1379	3.17
4	12	0.12	560	21.10	17.71	1.904	2428	7.11

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

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

4. Mathematical Models

Considering the experimental results, and the research methodology mentioned [4], equation systems necessary for determining the proposed mathematical models are:

$$\begin{cases} \lg 1652 = \lg C_F + x_F \lg 8 + y_F \lg 0.12 + z_v \lg 14.07 \\ \lg 2187 = \lg C_F + x_F \lg 8 + y_F \lg 0.20 + z_v \lg 14.07 \\ \lg 1379 = \lg C_F + x_F \lg 8 + y_F \lg 0.12 + z_v \lg 22.61 \\ \lg 2428 = \lg C_F + x_F \lg 12 + y_F \lg 0.12 + z_v \lg 21.10 \end{cases} \quad (8)$$

$$\begin{cases} \lg 3.60 = \lg C_M + x_M \lg 8 + y_M \lg 0.12 + z_M \lg 14.07 \\ \lg 4.99 = \lg C_M + x_M \lg 8 + y_M \lg 0.20 + z_M \lg 14.07 \\ \lg 3.17 = \lg C_M + x_M \lg 8 + y_M \lg 0.12 + z_M \lg 22.61 \\ \lg 7.11 = \lg C_M + x_M \lg 12 + y_M \lg 0.12 + z_M \lg 21.10 \end{cases} \quad (9)$$

Solving the equations systems, force and torque models obtained are:

$$F = 911.40 \cdot D^{1.33} a_f^{0.55} v^{-0.38} \text{ [N]} \quad (10)$$

$$M = 0.495 \cdot D^{1.95} a_f^{0.64} v^{-0.27} \text{ [Nm]} \quad (11)$$

4 Conclusion

Stainless steels represent very important materials, with special characteristics that require lot of research. One aspect of interest is their machinability so, the values, as well as dependence relations of cutting forces and torques are worth to be determined. When the above mentioned elements have to be studied, special devices are designed and, a key role in obtaining good results is that of appropriate signals processing.

So, when determining mathematical models of cutting force and torque, a very important attention has to be paid in designing the measuring device, specially, to transducers type, position and coupling.

There were carried out researches on axial cutting force and torque in drilling 2MoCrNi175 stainless steel. It can be stated that, for the obtained mathematical models, the higher influence on the dependent variable (F, or M) was that of cutting tool diameter, D, while, the lowest influence, was that of cutting speed, v, but, it was a reverse one. 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).

Further research should be developed so as, to improve the experiment design, the regression analysis and, even, implement the obtained results into an automated optimization system .of the manufacturing process.

References:

[1] Sarawut Sujitjorn, Wirote Sangtungtong, "Combined sliding-mode speed-torque observer" s[th] *WSEAS* International Conference ICOSSSE 2005, ISSN 1790-5117, Spain, December, 2005

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

[3] Iliescu M.,Vlase A., "New Mathematical Models of Axial Cutting Force and Torque in Drilling 20MoCr130 Stainless Steel"10[th] WSEAS International Conference, MACMESE'08, pag. 210-215, ISSN 1790-2769, Bucharest, November, 2008

[4] Ghionea A., Vlase A, Ghionea I, Wear Evaluation of Cutting Edge and Cutting Speed in Drilling Process of Some Manganese Steel, Proceedings of 18[th] 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.