CALCULUS RELATIONS OF THE AXIAL CUTTING FORCE AND CUTTING MOMENT AT WIDENING OF THE STEEL X6CrNiTi18-10

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Abstract: This paper presents a series of experimentally establish data at widening of the stainless steel X6CrNiTi18-10 and the means for the determination of the axial cutting force and cutting moment with respect to the specific working conditions. The experimental data and their following processing represent the original contribution of the authors to determination of the calculus relations of the axial cutting force and cutting moment for widening of the studied steel. These were modified with respect to the relations available in the technical literature for common steels. The presented results can be taken into consideration in the educational studies and in the theoretical technical research. They can be implemented in the manufacturing activity.
Key words: widening, force, moment, steel, polytropic.

1. INTRODUCTION

The stainless steels are used more and more in various key domains of the technique. The processing of these steels is determined by their specific physical-chemical characteristics and by their technological properties (Roukema & Alintas, 2006), (Vlase, 1977).

The great difficulties for the cutting of the stainless steels involved intense studies to create new materials for tools and sensible choice for the tools geometric parameters and cutting regime (Tănase, 2009), (Trent & Wright, 2000).

On the other hand, due to the high costs of these steels their machinability should be studied using rapid cutting methods capable of assuming minimum tool and material requirements (Barlier & Girardin, 1999), (Vlase et al., 2007).

With this object in view, this paper expounds a series of experimentally found data concerning the widening of the stainless steel X6CrNiTi18-10 and the ways and means to determine the cutting forces and the cutting moments.

The axial cutting force function and the cutting moment function will be determined in the terms of four independent variables (the diameter *D*, the feed *f*, the depth a_p, the tool speed *v*) for widening of the analyzed stainless steel, with respect to the specific working conditions.

2. MEANS AND CONDITIONS USED FOR EXPERIMENTS

The tests were performed using a stand of determinations for recording the values of the force variations and the values of the moment variations at different splintering parameters, consisting of the following (Figure 1): a build dynamometer with resistive tensometer transducers for measuring the forces; a MGC amplifier, produced by Hottinger Baldwin Messtechnic; a data acquisition board type DAQ Pad 6020E; PC; LabWIEW software.

The build dynamometer is a rotating one being fixed by a taper shank in the tapered bore of the drilling shaft. A spring collet type force and moment detecting element was adapted for the dynamometer construction. On the perimeter of the elastic detecting element four equidistant resistive transducers were placed, inclined at 45^0 with respect to generatrix, in opposite, alternative successively. By using this placement of the transducers, and by connecting them to a bridge, highest measurement sensitivity has been achieved. In order to calibrate the dynamometer, the following were used: a standard dynamometer; a taper rod (TC-01-03), axial and tangential loading device.

The means and the cutting conditions during the experiments are given below:

- the machine tool: a GC_0 32 DM3 drilling device, the dimensions of the mass are 480×420 and a Morse cone 4 was used;
- the cutting equipment: Rp5 high-speed steel spiral drill with the Rockwell Hardness Number = 62;
- the geometric features of the drill have met the requirements of the R1370/2-69 standard, A_1 type cutting, with diameters within the range 10 through 30 mm;
- the cooling and lubricating fluid: P 20% emulsion.

The Table 1 shows the chemical characteristics of the stainless steel X6CrNiTi18-10. The Table 2 contains

Fig.1. The experimental stand of determinations

Table 1. Percentage chemical composition [%]

C	Cr	Ni	Ti	Si	Mn	S	P
0.08	18	10.5	0.6	1.0	2.0	0.018	0.027

Table 2. Physical characteristics

Density (at 20^0 C) [kg/dm^3]	Elasticity modulus (at 20^0 C) [GPa]	Heat conductivity [W/m ^{0}K]	Specific heat [J/kg ^{0}K]	Electric resistivity [Ω mm^2/m]
7.86	208	16	500	0.74

Table 3. Mechanical characteristics (at 20^0 C)

Stainless steel type	Tensile strength R_m [MPa]	Flowing limit R_{02} [MPa]	Elongation A [%]	Hardness [HB]
X6CrNiTi18-10	620	200	40	260

the physical characteristics of this steel. In the Table 3 are presented the mechanical characteristics of the studied steel.

3. EXPERIMENTAL RESULTS AND DATA PROCESSING FOR THE AXIAL CUTTING FORCE

The technical literature (Schnadt, 1991), (Vlase, 1977) provided the equation (1), which has been the starting point in the analysis of the axial cutting forces for widening:

$$F_z = C_F \cdot D^{x_F} \cdot f^{y_F} \cdot a_p^{z_F} \quad [\text{N}] \qquad (1)$$

where: D is the final diameter; f is the feed; a_p is the depth; C_F is a constant; x_F, y_F, z_F are polytropic exponents.

This equation has proved to be inappropriate since after the practical estimation of the exponents and constants, several tests determinations have been performed and have showed a wide result scattering noted under the same cutting conditions. The problem is that during the steel machining at various speeds, different parameter values were recorded even if all the other machining conditions are kept constant. Therefore, it has led to introduce a speed factor:

$$F_z = C_F \cdot D^{x_F} \cdot f^{y_F} \cdot a_p^{z_F} \cdot v^{w_F} \quad [\text{N}] \qquad (2)$$

In order to the C_F constant and the x_F, y_F, z_F, w_F polytropic exponents were estimated, the equation (2) has been linearized by using the logarithm. It obtained the equation:

$$\begin{aligned} \lg F_z = \lg C_F + x_F \cdot \lg D + y_F \cdot \lg f + \\ + z_F \cdot \lg a_p + w_F \cdot \lg v \end{aligned} \qquad (3)$$

The Table 4 shows a selection of the most conclusive experimental results obtained for the studied stainless steel.

If the data of the first five experiments from the Table 4 are substituted in the equation (3), then a linear inhomogeneous system of five equations with five unknowns (x_F, y_F, z_F, w_F, lgC_F) is obtained:

Table 4. Experimental results

Exp. No	Initial diameter D_i [mm]	Final diameter D [mm]	Feed f [mm/rot]	Depth a_p [mm]	Rotation n [rot/min]	Speed v [m/min]	Cutting force F_z [N]	Cutting moment M [Nm]
1	16	24	0.12	4	224	16.88	1929	26.90
2	12	16	0.20	2	355	17.83	874	13.78
3	16	24	0.32	4	224	16.88	2490	40.61
4	18	24	0.12	3	224	16.88	1366	23.16
5	16	24	0.12	4	355	26.75	2225	27.78
6	14	20	0.20	3	355	22.30	1630	23.26
7	14	24	0.12	5	224	16.88	2540	30.40

$$\begin{cases} \lg C_F + x_F \lg 24 + y_F \lg 0.12 + z_F \lg 4 + \\ \quad + w_F \lg 16.88 = \lg 1929 \\ \lg C_F + x_F \lg 16 + y_F \lg 0.20 + z_F \lg 2 + \\ \quad + w_F \lg 17.83 = \lg 874 \\ \lg C_F + x_F \lg 24 + y_F \lg 0.32 + z_F \lg 4 + \\ \quad + w_F \lg 16.88 = \lg 2490 \\ \lg C_F + x_F \lg 24 + y_F \lg 0.12 + z_F \lg 3 + \\ \quad + w_F \lg 16.88 = \lg 1366 \\ \lg C_F + x_F \lg 24 + y_F \lg 0.12 + z_F \lg 4 + \\ \quad + w_F \lg 26.75 = \lg 2225 \end{cases} \quad (4)$$

The system (4) has the following solution: $C_F = 112$; $x_F = 0.27$; $y_F = 0.26$; $z_F = 1.2$; $w_F = 0.31$.
The formula of the axial cutting force for the widening of the stainless steel X6CrNiTi18-10 is obtained by inserting the above solution in the equation (2):

$$F_z = 112 \cdot D^{0.27} \cdot f^{0.26} \cdot a_p^{1.2} \cdot v^{0.31} \quad [\text{N}] \qquad (5)$$

The data of the last two experiments, included in the Table 4, allow the verification of the formula from the relation (5).
By tracing the diagrams of the cutting axial force variation with respect to the work parameters, using *Maple* software (Blăjină, 2001), the resulted diagrams are shown in Figures 2 to 7 valid only for widening of the stainless steel X6CrNiTi18-10 with a Rp5 high-speed steel spiral.
Figure 2 shows the variation of the axial cutting force depending on the feed, for different tool diameters; the force increases with the feed. Figure 3 shows the variation of the cutting force depending on the tool diameter, for different depths; the force increases with the diameter. Figure 4 shows the variation of the axial cutting force depending on the feed, for different tool speeds; the force increases with the feed. Figure 5 shows the variation of the axial cutting force depending on the depth, for different tool speeds; the force increases exponentialy with the depth. Figure 6 shows the variation of the axial cutting force depending on the tool speed, for different diameters; the force increases with the tool speed. Figure 7 shows the variation of the cutting force depending on the tool speed, for different feeds; the force increases with the tool speed.

4. EXPERIMENTAL RESULTS AND DATA PROCESSING FOR THE CUTTING MOMENTS

The technical literature (Sarawut & Wirote, 2005), (Vlase, 1977) provided the equation (6), which has been the starting point in the analysis of the cutting moments for widening:

$$M = C_M \cdot D^{x_M} \cdot f^{y_M} \cdot a_p^{z_M} \quad [\text{Nm}] \qquad (6)$$

where: D is the final diameter; f is the feed; a_p is the depth; C_M is a constant; x_M, y_M, z_M are polytropic exponents.
This equation has proved to be inappropriate since after the practical estimation of the polytropic exponents and the constants, several tests determinations have been performed and have showed a wide result scattering under the same cutting conditions (Vlase et al., 2009).
The problem is that during the steel machining at various speeds, different parameter values were recorded even if all the other machining conditions were kept constant. It has led to introduce a speed factor thus:

$$M = C_M \cdot D^{x_M} \cdot f^{y_M} \cdot a_p^{z_M} \cdot v^{w_M} \quad [\text{Nm}] \qquad (7)$$

In order to the C_M constant and the x_M, y_M, z_M, w_M polytropic exponents were estimated, the equation (7) has been linearized by using the logarithm. It obtained the equation:

$$\begin{aligned} \lg M = \lg C_M + x_M \cdot \lg D + y_M \cdot \lg f + \\ + z_M \cdot \lg a_p + w_M \cdot \lg v \end{aligned} \qquad (8)$$

If the data of the first five experiments from the Table 4 are substituted in the equation (8), then the following linear inhomogeneous system of five equations with five unknowns (x_M, y_M, z_M, w_M, $\lg C_M$) is obtained:

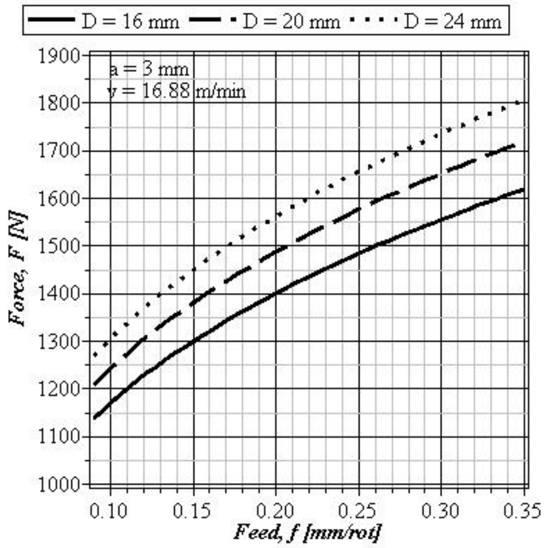

Fig.2. The force variation depending on the feed for different tool diameters

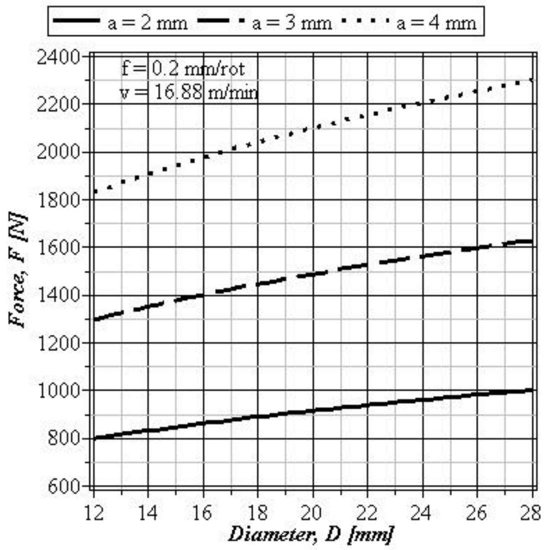

Fig.3. The force variation depending on the tool diameter for different depths

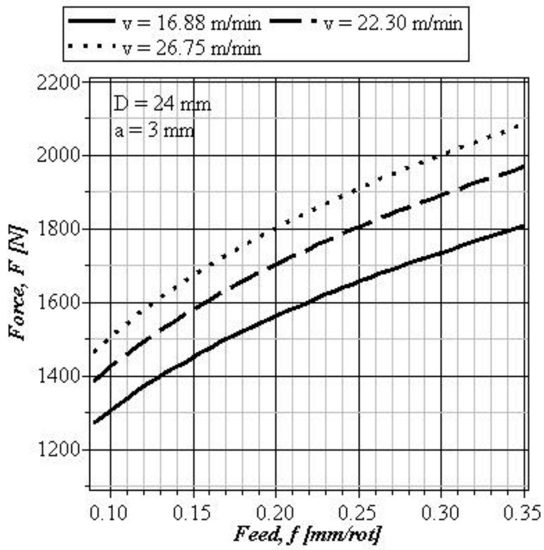

Fig.4. The force variation depending on the feed for different tool speeds

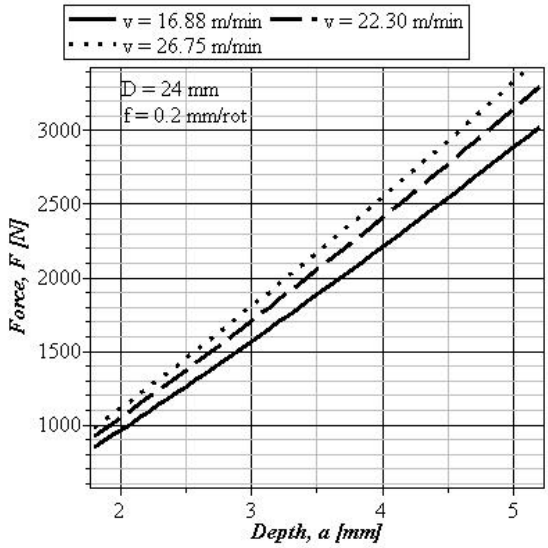

Fig.5. The force variation depending on the depth for different tool speeds

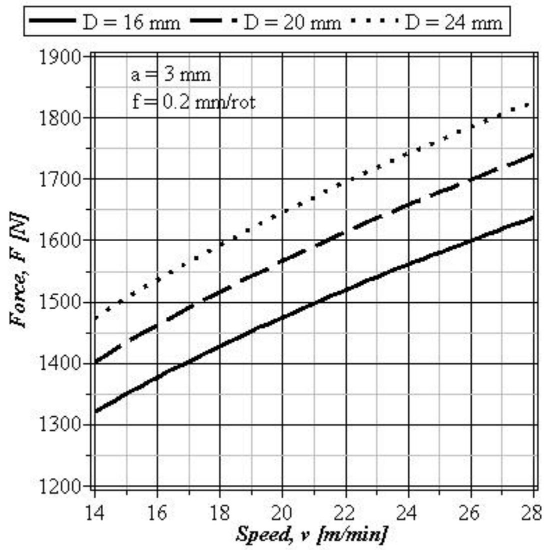

Fig.6. The force variation depending on the tool speed for different diameters

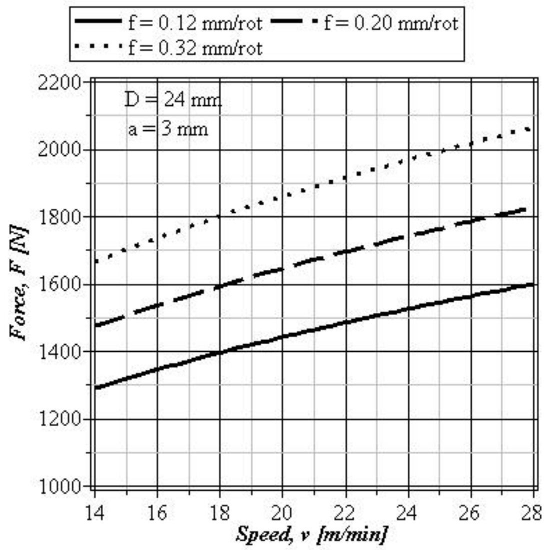

Fig.7. The force variation depending on the tool speed for different feeds

$$\begin{cases} \lg C_M + x_M \lg 24 + y_M \lg 0.12 + z_M \lg 4 + \\ \quad + w_M \lg 16.88 = \lg 26.90 \\ \lg C_M + x_M \lg 16 + y_M \lg 0.20 + z_M \lg 2 + \\ \quad + w_M \lg 17.83 = \lg 13.78 \\ \lg C_M + x_M \lg 24 + y_M \lg 0.32 + z_M \lg 4 + \\ \quad + w_M \lg 16.88 = \lg 40.61 \\ \lg C_M + x_M \lg 24 + y_M \lg 0.12 + z_M \lg 3 + \\ \quad + w_M \lg 16.88 = \lg 23.16 \\ \lg C_M + x_M \lg 24 + y_M \lg 0.12 + z_M \lg 4 + \\ \quad + w_M \lg 26.75 = \lg 27.78 \end{cases} \tag{9}$$

The system (4) has the following solution: $C_M = 0.42$; $x_M = 1.3$; $y_M = 0.42$; $z_M = 0.52$; $w_M = 0.07$.
The formula of the cutting moment for the widening of the steel X6CrNiTi18-10 is obtained by inserting this solution in the equation (8):

$$M = 0.42 \cdot D^{1.3} \cdot f^{0.42} \cdot a_p^{0.52} \cdot v^{0.07} \quad \text{[Nm]} \tag{10}$$

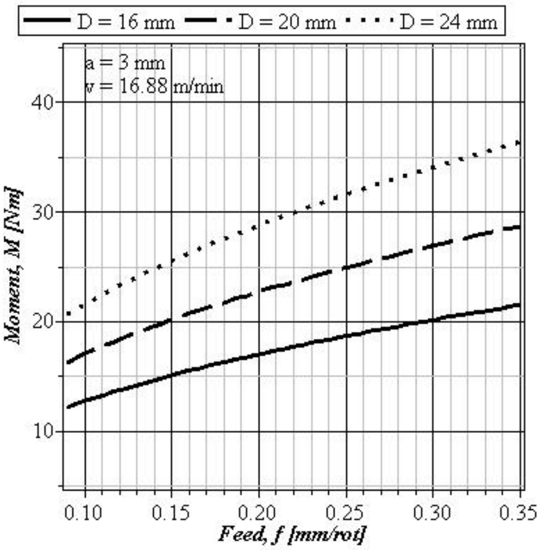

Fig.8. The moment variation depending on the feed for different tool diameters

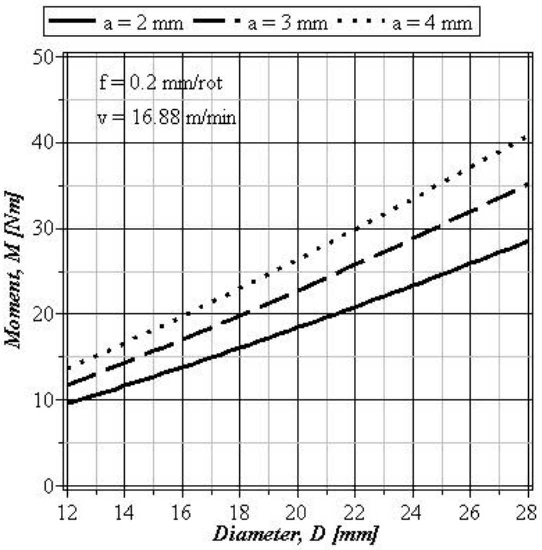

Fig.9. The moment variation depending on the tool diameter for different depths

The data of the last two experiments, included in the Table 4, allow the verification of the formula from the relation (10).
By tracing the diagrams of the cutting moment variation with respect to the work parameters, using *Maple* software, the resulted diagrams are shown in Figures 8 to 13 valid only for widening of the steel X6CrNiTi18-10 with a Rp5 high-speed steel spiral.
Figure 8 shows the variation of the cutting moment depending on the feed, for different diameters; the moment increases with the feed. Figure 9 shows the variation of the cutting moment depending on the diameter, for different depths; the moment increases exponentialy with the diameter. Figure 10 shows the variation of the moment depending on the feed, for different speeds; the moment increases with the feed. Figure 11 shows the variation of the cutting moment depending on the depth, for different feeds; the moment increases with the depth. Figure 12 shows

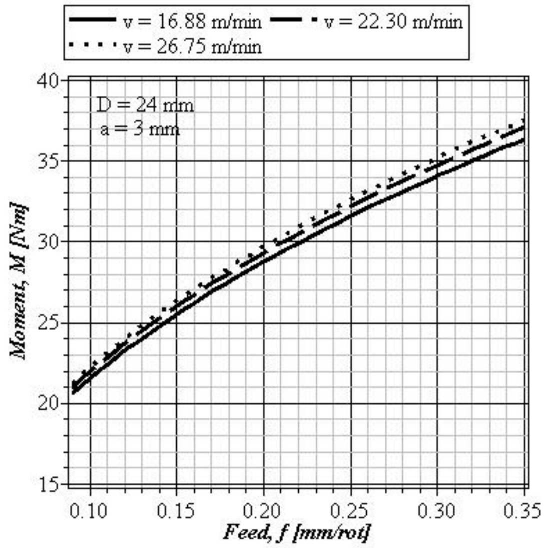

Fig.10. The moment variation depending on the feed for different tool speeds

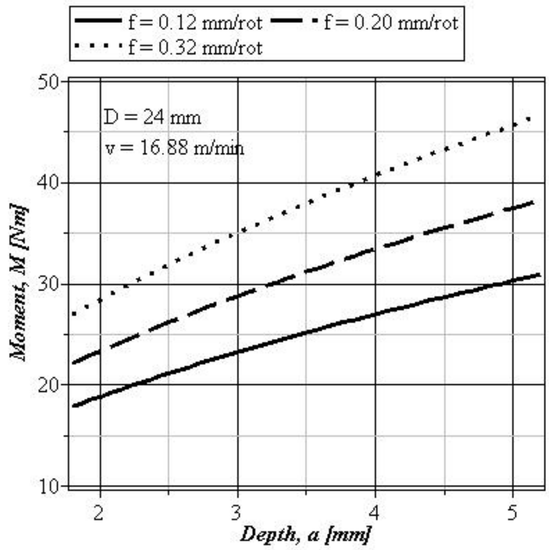

Fig.11. The moment variation depending on the depth for different feeds

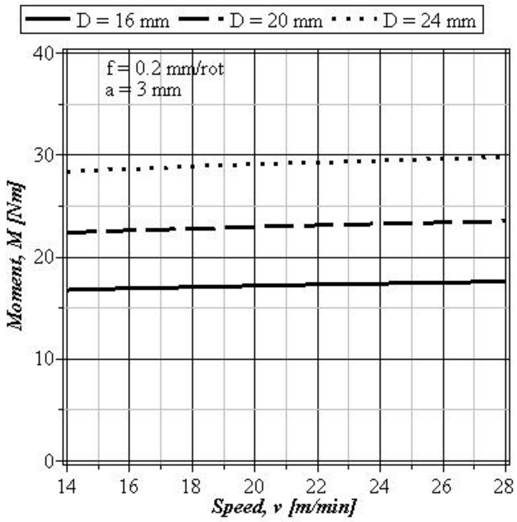

Fig.12. The moment variation depending on the tool speed for different diameters

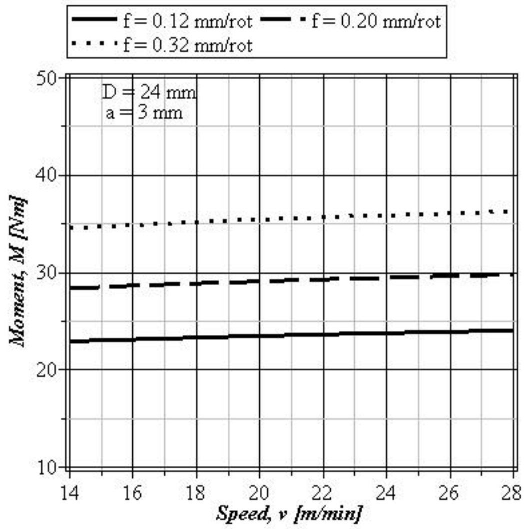

Fig.13. The moment variation depending on the tool speed for different feeds

the variation of the cutting moment depending on the tool speed, for different diameters; the moment increases with the tool speed. Figure 13 shows the variation of the cutting moment depending on the tool speed, for different feeds; the moment increases with the tool speed.

5. CONCLUSIONS

The experimental data and their processing represent the contribution of the authors to the estimation of the polytropic exponents and to the assessment in terms of structure of the calculus relations for the axial cutting force and for the cutting moment at the widening of the stainless steel X6CrNiTi18-10. For the determination of the force and the moment at the widening of the steel a special dynamometer was designed and manufactured. It was a rotative dynamometer fixed in the tapered bore of the drilling shaft foreseen with tensometer transducers attached to an elastic element. Measuring range of the forces and the moments permitted tests with diameters within the range 10 through 30mm.

By many experimental tests, it was demonstrated the necessity of modifying the structure of the cutting force calculation relation and the structure of the cutting moment calculation relation, found in the technical literature, meaning that the tool speed has to be included with respect to equations (2) and (7).

The experimental data and the diagrams prove the variation of the cutting axial force and the cutting moment values depending on the parameters of the cutting technology.

The results presented in this study can be taken into consideration in the educational studies and in the theoretical technical research. Also, they can be readily implemented in the manufacturing activity. Our further studies aim these problems for another steels classes.

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