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NEW RELATION OF THE CUTTING FORCES FOR TURNING OF THE STAINLESS STEEL 13H11N2V2MFS

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Abstract: *Due to their exceptional characteristics of durability, hygienic, recyclable and low percent of toxicity characteristics, the stainless steels remain one of the most used groups of materials around the world. In order to ease the researches carried out and the decisions making process when selecting the optimum material within a technological process, it is crucial to understand the mathematical functions of cutting process during various operations. The paper presents a series of experimentally found data concerning the turning of the stainless steel 13H11N2V2MFS and the ways and means to determine the cutting forces with respect to the specific working conditions. The experimental data and their subsequent processing represent the contribution of the authors to the estimation of the polytropic exponents and to the assessment in terms of structure of the cutting forces equation. Afterwards, the paper presents the graphs for the variation of the cutting force components with the parameters of the cutting technology. The obtained results can be implemented in further research, in order to increase the productivity of steel machining.*

Key words: *cutting force, stainless steel, turning, polytropic exponents.*

1. INTRODUCTION

The researches in cutting domain have as purpose the cutting process economic optimization. In time, these allowed to create new materials for cutting tools and sensible choice for tools geometric parameters and cutting regime [5]. The use of stainless steels is increasing at a rapid rate in various technical fields. It is well known that, owing to some specific physic-mechanical properties, it is often very problematic in practice to cut stainless steels in industry [2, 6]. At the same time, owing to the high costs of these steels, their machinability should be studied using rapid cutting methods capable of assuming minimum tool and material requirement [3]. With this object in view, the present paper expounds a series of experimentally found data concerning the turning of the stainless steel 13H11N2V2MFS. The new equation is to be used this way for any other future determination of forces while processing other materials, especially in stainless steels applications.

Our main objective in this field represents developing a general methodology for researching the cutting conditions, and finding a global indicator of processing.

2. METHODS, EQUIPMENT AND CUTTING CONDITIONS

The tests were performed using a dynamometer with resistive tensometer transducers for the determination of the cutting forces. A spring collets type force detecting element was adapted for the dynamometer construction. On the perimeter of the elastic detecting element, four equidistant resistive transducers were placed, inclined at 45º with respect to generator, 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 (available in the design laboratory of the department);
- a taper rod (TC-01-03), axial and tangential loading device (available in the laboratory of the department). The loading of the dynamometer was done on the axial direction and the tensometer bridge gradations were noted. The tests were repeated five times. The tensometer bridge values have an almost linear variation related to applied forces. Average constant calibration is K_F = 130 [N/V].

Table 1 shows the chemical characteristics of the steel 13H11N2V2MFS. Table 2 shows the mechanical characteristics of this studied steel. The cutting conditions during the experiments are given below:

(1) The machine tool: a SN 400 × 1500 normal lathe with P = 7.5 kW, range of revolutions 12...1500 rot/min with 22 steps, and range of tools travels 0.06...3.52 mm/rot with 30 steps.

(2) The cutting equipment: knife with mechanical fixing, geometry, carbide M20.

(3) The geometric features of the knife: α = 8º, γ = 0º, r = 1.5 mm.

(4) The cooling and lubricating fluid: P 20% emulsion.

3. THE EXPERIMENTAL RESULTS AND ANALYSES

Technical literature [5] provided equation (1), which has been the starting point in the analysis of the cutting forces:

$$F = C_F \cdot a_p^{\,x} \cdot f^{\,y} \cdot \quad [N]. \tag{1}$$

Table 1

The chemical composition of the stainless steel 13H11N2V2MFS

Chemical composition [%]									
C	**Mo**	**Ni**	**Cr**	**Mn**	**Si**	**S**	**P**	**V**	**N**
0.12	2.0	2.5	11.5	0.7	0.9	0.02	0.3	0.3	0.02

Table 2

The mechanical characteristics of the stainless steel 13H11N2V2MFS

Tensile Strength, *Rm*, [N/mm^2]	**Flowing Limit, R_{02},** [N/mm^2]	**Elongation, δ,** [%]	**Hardness,** *HB*
1080	788	9.2	2.85

Table 3

Experimental Results

Stainless steel 13H11N2V2MFS								
Exp. Nr.	**Cutting depth, a_p,** [mm]	**Feed, *f*,** [mm/rot]	**Rotation, *n*,** [rot/min]	**Probe diameter, *d*,** [mm]	**Cutting speed, v_c,** [m/min]	**Force *** [N]		
						F_x	F_y	F_z
1	0.5	0.10	250	68	53.38	171.92	349.03	93.05
2	1.0	0.20	250	68	53.38	406.06	835.91	248.99
3	1.0	0.10	250	68	53.38	283.18	591.08	162.01
4	1.0	0.15	350	68	74.73	346.48	713.76	206.57
5	0.5	0.25	250	68	53.38	276.85	551.86	164.23
6	1.5	0.20	500	68	106.76	533.64	1104.96	338.48
7	0.5	0.10	630	68	134.52	167.68	335.74	90.93

* The system of coordinates is according to the ISO standard

where a_p is the cutting depth and f is the cutting feed. This equation has proved to be inappropriate since after the practical estimation of the polytropic exponents and constants, several tests determinations have been performed and have showed a wide result scattering 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 were kept constant [7]. It has led to introduce a speed factor:

$$F = C_F \cdot a_p^{\,x} \cdot f^{\,y} \cdot v_c^{\,z} \quad [N], \tag{2}$$

In order to the C_F constant and the x, y, z polytropic exponents were estimated, the equation (2) has been linearized by using the logarithm:

$$\lg F = \lg C_F + x \lg a_p + y \lg f + z \lg v_c. \tag{3}$$

Table 3 above shows a selection of the most conclusive machined steel samples of the stainless steel 13H11N2V2MFS. If the data included in Table 3 are substituted in the equation (3), a linear inhomogeneous system of four equations with four unknowns (x, y, z, $\lg C_F$) is obtained, for every cutting force component, F_x, F_y and F_z.

The system for the force component F_x has the form:

$$\begin{aligned} &\lg C_F + x\lg 0.5 + y\lg 0.10 + z\lg 53.38 = \lg 171.92, \\ &\lg C_F + x\lg 1.0 + y\lg 0.10 + z\lg 53.38 = \lg 283.18, \\ &\lg C_F + x\lg 0.5 + y\lg 0.25 + z\lg 53.38 = \lg 276.85, \\ &\lg C_F + x\lg 0.5 + y\lg 0.10 + z\lg 134.52 = \lg 167.68. \end{aligned} \tag{4}$$

And it has the following four solutions: $C_F = 1044$; $x = 0.72$; $y = 0.52$; $z = -0.027$.

The formula of the cutting force component F_x for the turning of the stainless steel 13H11N2V2MFS is obtained by inserting these solutions in the equation (2):

$$F_x = 1044 \cdot a_p^{\,0.72} \cdot f^{\,0.52} \cdot v_c^{\,-0.027} \quad [N]. \tag{5}$$

Similarly, we obtain the following formulas for the cutting force components F_y and F_z, for the turning of the stainless steel 13H11N2V2MFS:

$$F_y = 2209 \cdot a_p^{\,0.76} \cdot f^{\,0.5} \cdot v_c^{\,-0.042} \quad [N], \tag{6}$$

$$F_z = 746 \cdot a_p^{\,0.8} \cdot f^{\,0.62} \cdot v_c^{\,-0.025} \quad [N]. \tag{7}$$

The graphs of forces variations F_y (we choose to represented F_y because it is the most significant) according to working parameters are shown in figures from 1 to 6.

Figure 1 shows the variation of the force depending on the cutting speed, for different feeds. The parameter kept fixed was the cutting depth, and we varied the cutting feed and the cutting speed. We can observe that the values slowly decrease in an exponentially way.

Figure 2 shows the exponential decreasing of the force F_y depending on the cutting speed. It can be noticed that for a depth of 0.5 mm, the necessary force for turning the material is lower comparing to the same speed, but a higher depth, of 1 mm and 1.5 mm.

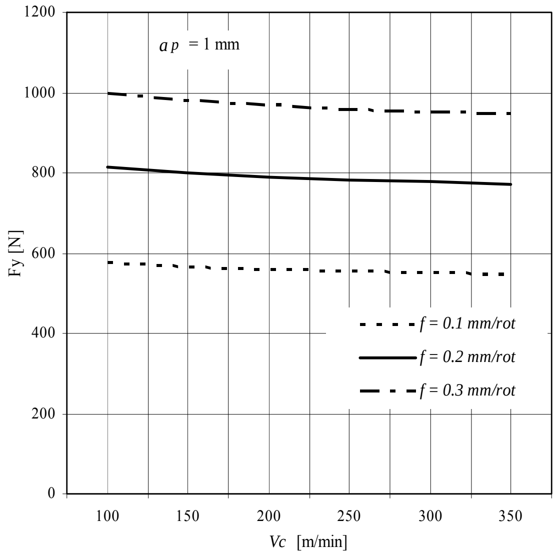

Fig. 1. The force F_y variation depending on the cutting speed for different feeds.

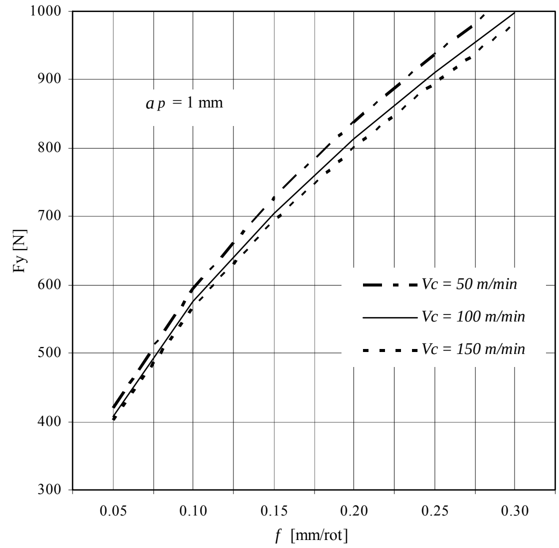

Fig. 3. The force F_y variation depending on the cutting feed for different speeds.

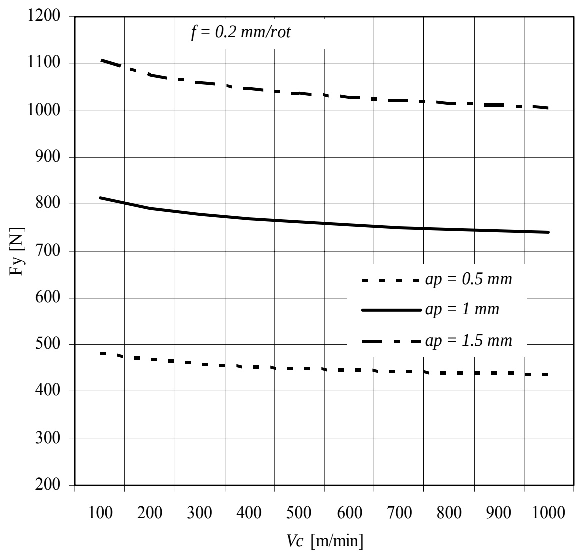

Fig. 2. The force F_y variation depending on the cutting speed for different depths.

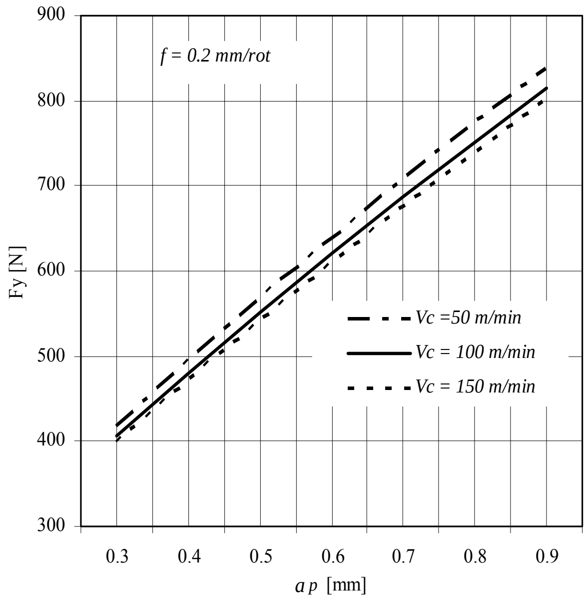

Fig. 4. The force F_y variation depending on the cutting depth for different speeds.

According to the results obtained and their graphic representation, a higher force can be reached around 1100 N, under the conditions of a speed of 50 m/min. In the same way, a low force can be obtained around 420 N, for a high speed of approximately 1050 m/min.

From Fig. 3 to Fig. 6, we observe the exponentially increase of the force F_y respectively depending on cutting feed; cutting depth; for different cutting speed, cutting depth and cutting feed. That variation is almost linear in Fig. 4.

Figure 4 shows the exponential increasing of the force F_y depending on the cutting depth. It can be noticed that for a speed of 50 m/min, the necessary force for turning the material is higher comparing to the same depth, but a higher speed, of 100 m/min and 150 m/min.

According to the results obtained and their graphic representation, a higher force can be reached around 840 N, under the conditions of a speed of 50 m/min and a depth of 0.9 mm.

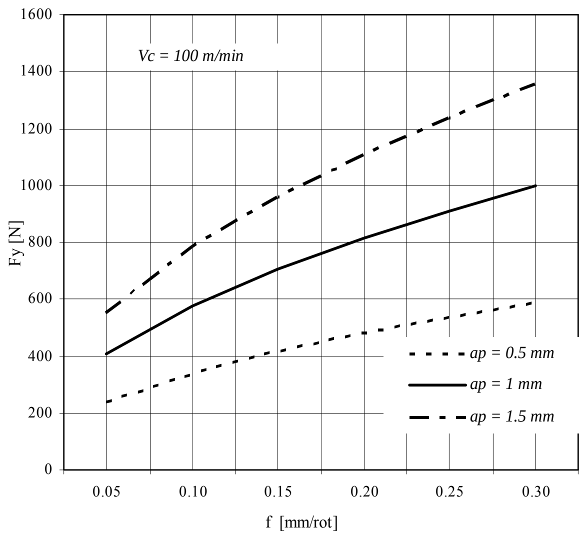

Fig. 5. The force F_y variation depending on the cutting feed for different depths.

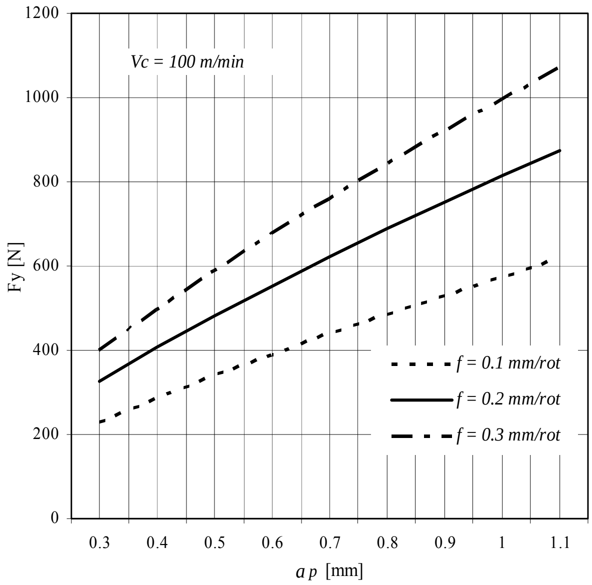

Fig. 6. The force F_y variation depending on the cutting depth for different feeds.

4. CONCLUSIONS

For this particular study, we had chosen the stainless steel 13H11N2V2MFS. For determining the cutting forces, we have chosen the complete mathematical functions, which include the cutting speed. Through logarithm processing, we have obtained linear equations, and by inserting the experimental results, we have gained simple systems of four equations, with four unknown parameters.

The analysis of the experimental data has led to the following conclusions:

- By many experimental tests, it was demonstrated the necessity of modifying the structure of the cutting force calculation relation found in the technical literature, meaning that the speed has to be included with respect to equations (2) and (5)-(7).
- For the cutting forces determination, a rotating dynamometer with tens meter transducers fixed on the elastic element was specially designed and fabricated, then mounted into the conical hole of the drilling machine, assuring though the necessary sensitivity in measuring the forces;
- The exponent of speed is negative value, and so the force is decreased in the same time with f, a_p and v.; a_p has the highest value, influencing the force the most out of the three exponents;
- The Table 3 shows very clearly the experimental results when measuring the forces, having set the cutting parameters. From these values, it can be seen that the forces vary within a large range of values, from 90 N to 592 N;
- Six graphs were drawn by combining one fixed parameter and varying other two. One of the varying parameters was considered the X axis and the other given three determined values;
- The results obtained here can be further used in standard studies for this particular stainless steel.

The final forms of the forces functions presented in this paper represent a standard in studying the cutting process and can be used for various materials and cutting conditions, proving in the same time the necessity of using the speed in determining various parameters of cutting process.

This study is one of the beginning steps for developing standard forces and moments functions for other materials.

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