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EXPERIMENTAL RESEARCH REGARDING THE INFLUENCE OF CUTTING PARAMETERS ON CUTTING FORCE IN TURNING OPERATION

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Abstract: The aim of the paper is to study and present the effect of cutting parameters such as feed and depth of cut on cutting forces in turning operation. The turning is a machining operation used in manufacturing processes for obtaining pieces of different shapes. In the cutting process, some movements are involved between the workpiece and the cutting tool. The forces developed are influenced by different factors, such as: workpiece material, tool material, tool geometry, cutting parameters and others. The results were plotted and some relations between the cutting parameters and cutting forces were developed. The results show that the depth of cut influence on cutting forces is bigger than the one of the feed.
Keywords: cutting forces, cutting parameters, turning, feed, depth of cut

1. INTRODUCTION

The turning is a machining operation used in manufacturing processes for obtaining pieces of different shapes. In the cutting process, some movements are involved between the workpiece and the cutting tool. The forces developed are influenced by different factors, such as: workpiece material, tool material, tool geometry, cutting parameters and others.

Studying of the dynamics of the cutting forces is of interest for the optimisation of the process and of the cutting conditions. Based on this, various characteristics of a machining process can be analysed the positioning of the cutting tool, the surface roughness, the stability of the process and the elimination of the vibrations.

The influence of the cutting parameters on cutting forces have been intensively studied by researchers. Sivaraman [1] studied the effect of cutting parameters on cutting force during turning multiphase micro alloyed steel. The result showed that feed and depth of cut influence more on cutting force than cutting speed. The interdependencies of different metal cutting parameters are examined in paper [2].

Rao [3] presented the significance of influence of speed, feed and depth of cut on cutting force and surface roughness while working with tool made of ceramic with an Al2O3+TiC matrix (KY1615)and the work material of AISI 1050 steel (hardness of 484 HV).

In research [4], influence of cutting parameters (speed, feed rate and depth of cutting) on the resultant cutting force while dry machining high-alloy steel on a conventional lathe is investigated.

The cutting forces are one of the inherent phenomena of the cutting process. Knowledge of cutting forces is very important because it leads to an efficient machining process through the proper selection of operating parameters, machine tools, fixtures, and tools [5].

Considering the example of a longitudinal turning, the components of the cutting force are presented in Figure 1. The components of the cutting force are expressed in accordance with the coordinate system XYZ, where Z axis is oriented towards the main moving direction (part rotation), X axis is oriented by the feed rate (in this case we are talking about a longitudinal feed rate) and Y axis is perpendicular on the other two axes.

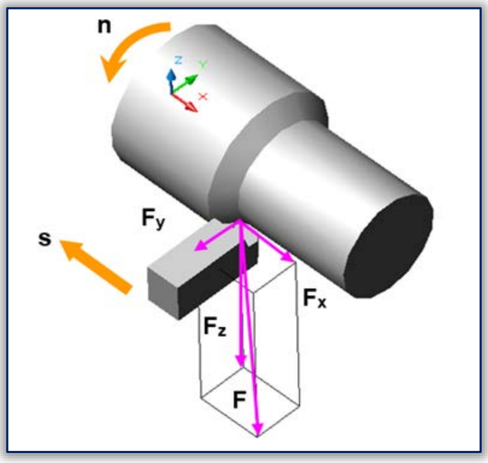

Figure 1. Components of the cutting force

F_z is the main component of the cutting force and acts against the workpiece during turning motion. F_x is the longitudinal component of the cutting force, also named feed force. It acts parallel to the workpiece turning axis. F_y is the radial component of the cutting force and it acts perpendicular to the turned surface [6,7].

By composing these three components if results the total cutting force, which is expressed, as a vector quantity, by equation (1):

$$\bar{F} = \bar{F}_z + \bar{F}_x + \bar{F}_y \tag{1}$$

As scalar, the total cutting force is expressed by equation (2):

$$F = \sqrt{F_z^2 + F_x^2 + F_y^2} \tag{2}$$

2. METHOD – Experimental setup

The experimental setup is presented in Figure 2. It consists of: a workpiece fixed on the turning machine, dynamometer with the cutting tool fixed in the elastic element, comparator watch.

The workpiece material used was AISI 1045 medium carbon steel. As regards the cutting tool it was considered a K carbide tool.

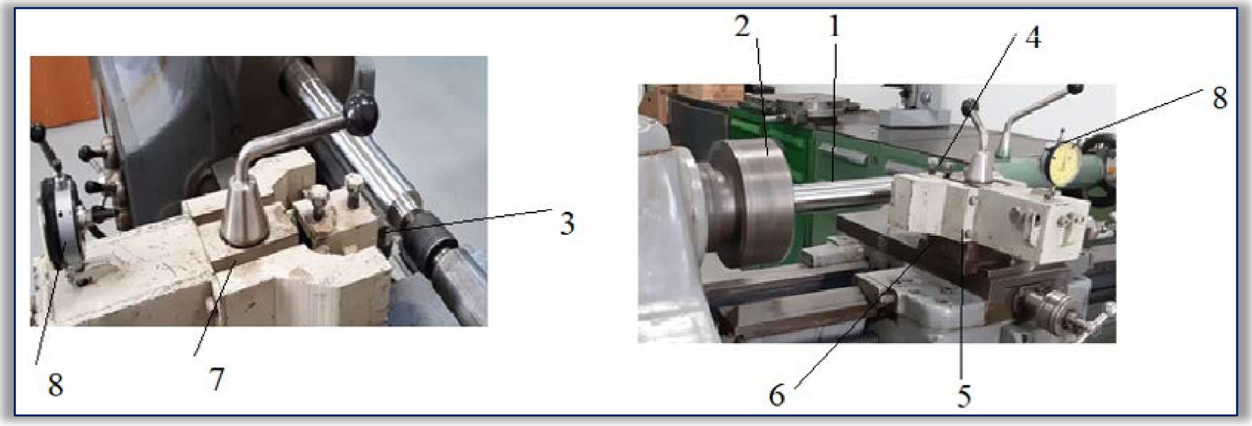

Figure 2. Experimental setup

The working principle: The workpiece (1) is fixed in the chuck (2) of the lathe and is turned with a tool (3), on the cylindrical external side. The tool is fixed with the screws (4) in an elastic element embedded in the dynamometer support (5). The dynamometer is positioned on the compound rest on the carriage of the leather (6).

During the turning operation, a cutting force is developed under the action of which the workpiece deforms in proportion to the size of the force. These deformations are amplified by means of the lever (7) and transmitted to the sensor of the comparator watch (8).

The experimental determination was carried out by changing the cutting parameters (feed rate and depth of cut), to measure the principal component of the cutting force (Fz).

Two series of measurements were made, as can be seen in table 1:

1. With feed rate (s) constant and depth of cut (t) variable
2. With depth of cut (t) constant and feed rate (s) variable

Table 1. Machining parameters

Measuring no.	Spindle rotation (rot/min)	Feed rate (mm/rot)	Depth of cut (mm)
1.	400	0.32	0.5
			1
			1.5
			2
2.	400	0.24	1
		0.32	
		0.56	
		0.72	

The force required to detach the chip must be known for both design machine tools, cutting devices and tools as well as for setting limit values of its size, depending on the strength or, most often, on the rigidity of the working piece.

In the case of turning processing, a series of relationships for the components of the cutting force were determined experimentally. The relation for main component of the cutting force Fz can be presented as follows:

$$F_z = C_{F_z} \cdot t^{x_{F_z}} \cdot s^{y_{F_z}} \cdot K_{F_z} \tag{3}$$

where C_{F_z}, x_{F_z}, y_{F_z} are coefficient and exponents experimental determined, and

K_{F_z} - global coefficient that takes into account the geometry, the material of the tool, the material of the working piece, etc

Starting from the relation (3) we obtain:

$$F_z = f(t) = C_1 \cdot t^{x_{Fz}} \quad (4)$$

$$F_z = f(s) = C_2 \cdot s^{y_{Fz}} \quad (5)$$

Applying logarithm on the relations (2) and (3), those are:

$$\lg F_z = \lg C_1 + x_{F_z} \cdot \lg t \quad (6)$$

$$\lg F_z = \lg C_2 + y_{F_z} \cdot \lg s \quad (7)$$

The exponents x_{F_z} și y_{F_z} represents the slopes of the lines resulting from the variation of the cutting force in relation to the cutting regime.

$$x_{F_z} = tg\alpha = \frac{\lg F_{t4} - \lg F_{t1}}{\lg t_4 - \lg t_1} \quad (8)$$

$$y_{F_z} = tg\beta = \frac{\lg F_{s4} - \lg F_{s1}}{\lg s_4 - \lg s_1} \quad (9)$$

3. RESULTS AND DISCUSSION

— Effects of feed

For the spindle speed of n=400 rot/min, the obtained results are shown in Table 2.

Table 2. Obtained results for the variation of s parameter

t=1 mm	lg s	Nr. div.	Fz (daN)	lg Fz
s1=0.24 mm/rot	-0.61979	3	15	1.176091
s2=0.32 mm/rot	-0.49485	4	20	1.30103
s3=0.56 mm/rot	-0.25181	5	25	1.39794
s4=0.72 mm/rot	-0.14266	6	30	1.47712

The evolution of the main component of the cutting force (Fz) in relation to feed rate evolution can be seen in the figure 3 and figure 4.

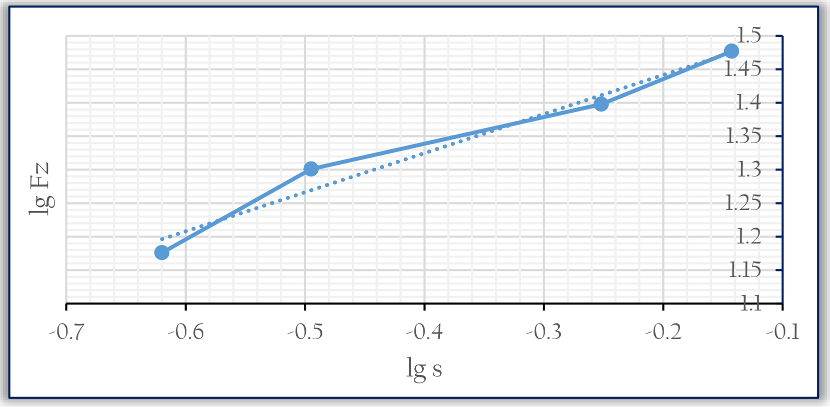

Figure 3. Plot of the force versus feed (n=400 rot/min).

Using relation (5), the slope of the line resulted by the variation of the feed rate can be calculated.

$$y_{F_z} = tg\beta = \frac{\lg F_{s4} - \lg F_{s1}}{\lg s_4 - \lg s_1} = 0.63093$$

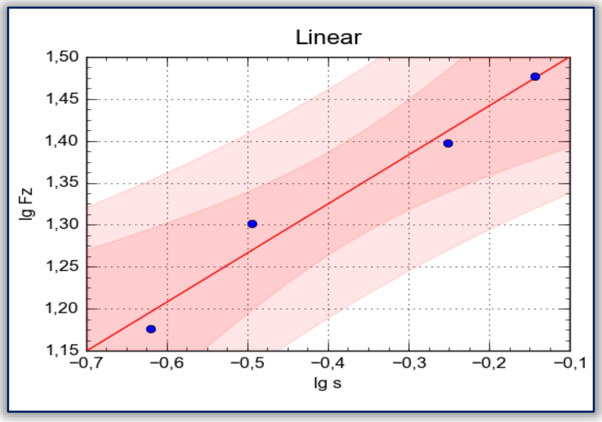

Figure 4. Linear regression

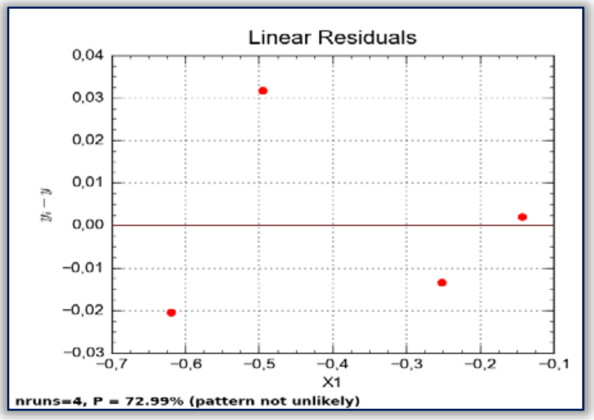

Figure 5. Residuals

Linear regression that best fits to the measured values, as developed by a specific software, is:

$$F(x)= 1.5584+0.5842*x \quad (10)$$

For the considered linear regression (relation 10), in table 3, can be seen the parameters values.

Table 3. Parameter values of the obtained regression

	Value	Std. Err.	Range (95% confidence)
a	1,558445	0,031543	1,422726 to 1,694164
b	0,584245	0,074723	0,262736 to 0,905754

The correlation coefficient (r) is 0,984 and the coefficient of determination (r^2) is 0.9683. Those values validate the function, as well as the graphical representation of the residual values of the function (Figure 5). In figure 6 is presented the polynomial regression, which fits best the obtained results.

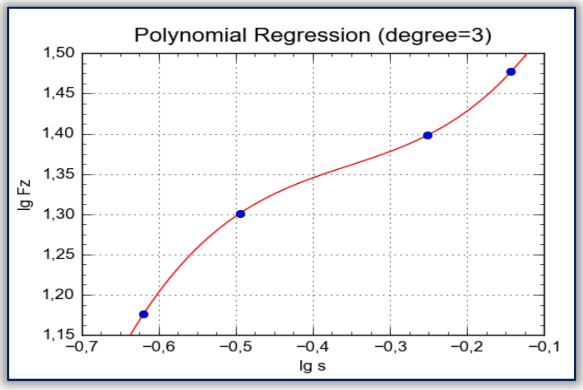

Figure 6. Polynomial regression

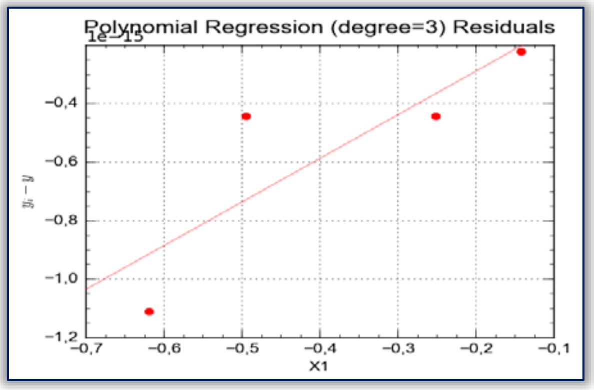

Figure 7. Residuals of the function

Polynomial regression that best fits to the measured values is, according to Curve expert software:

$$F(x)= 1{,}709+ 2{,}333*x+ 5{,}705*x^2+ 5{,}372*x^3 \quad (11)$$

The function is validates by the correlation coefficient(r) and the coefficient of determination (r^2). Those both have the value of 1, which means that the polynomial regression presented in relation (11) is suitable for the measured data. The residual values shown in Figure 7 also validate the relation (11). A comparison between the founded function, based on the measured values is presented in Figure 8.

For the spindle speed of n=800 rot/min, the obtained results are shown in Table 4 and plotted in figure 9.

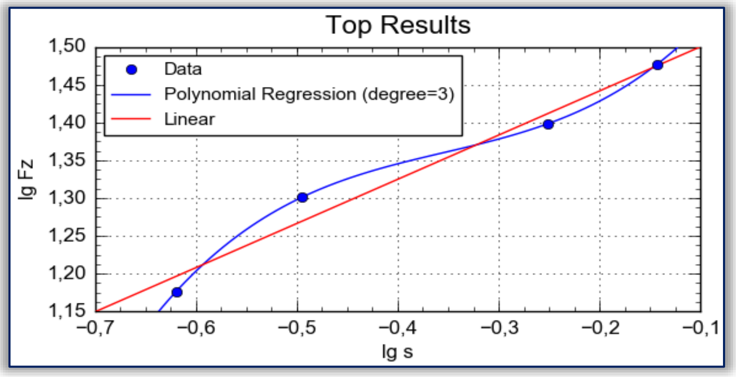

Figure 8. Comparison between linear and polynomial regression

Table 4. Obtained results for the variation of s parameter

t=1 mm	lg s	Nr. div.	Fz (daN)	lg Fz
s1=0.24 mm/rot	-0.61979	4	15	1.30103
s2=0.32 mm/rot	-0.49485	5	20	1.39794
s3=0.56 mm/rot	-0.25181	6	25	1.47712
s4=0.72 mm/rot	-0.14266	7	30	1.54406

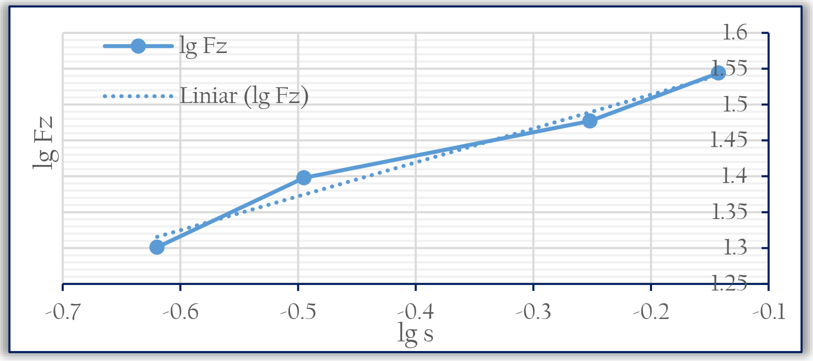

Figure 9. Plot of the force versus feed (n=800 rot/min).

Using relation (5), the slope of the line resulted by the variation of the feed rate can be calculated.

$$y_{F_z} = tg\beta = \frac{\lg F_{s4} - \lg F_{s1}}{\lg s_4 - \lg s_1} = 0.509$$

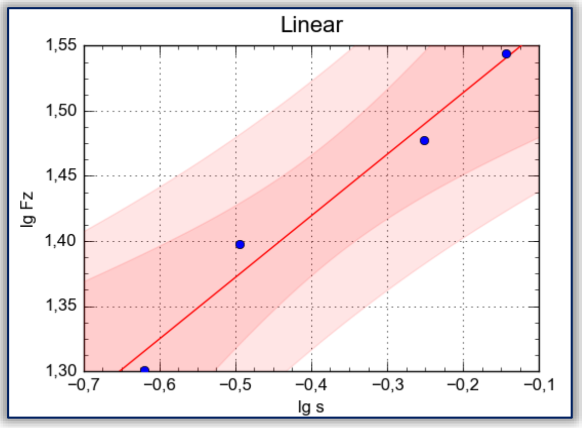

Figure 10. Linear regression

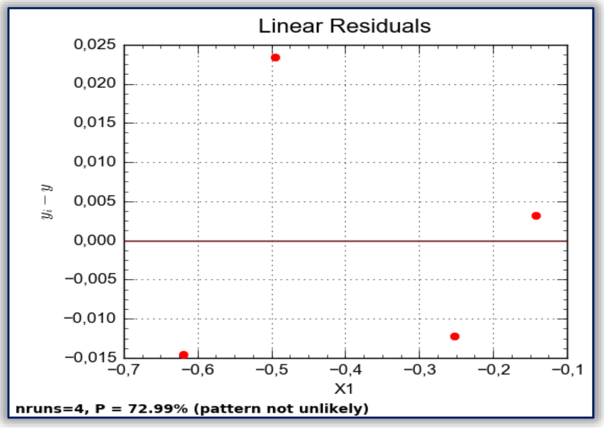

Figure 11. Residuals

Linear regression that fits to the measured values (figure 10) is:

$$F(x)= 1{,}608+ 0{,}472175*x \tag{12}$$

For the considered linear regression (relation 12), in table 5, can be seen the parameters values.

Table 5. Parameter values of the obtained regression

	Value	Std. Err.	Range (95% confidence)
a	1,608181	0,023867	1,505487 to 1,710874
b	0,472175	0,056540	0,228901 to 0,715449

The correlation coefficient (r) is 0.9859 and the coefficient of determination (r^2) is 0.9721, which validate the suitable function. The representation of the residual values also validates the function (figure 11).
In figure 12 is presented the polynomial regression, which fits best the obtained results.

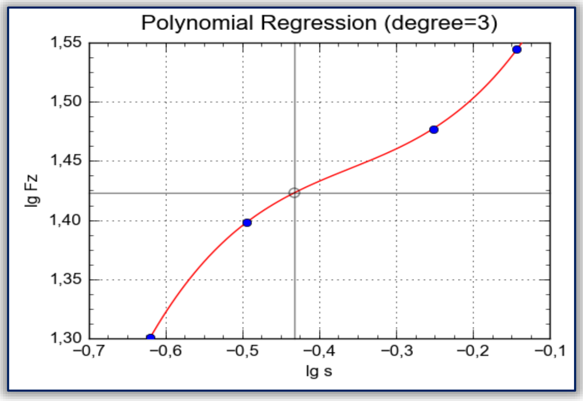

Figure 12. Polynomial regression

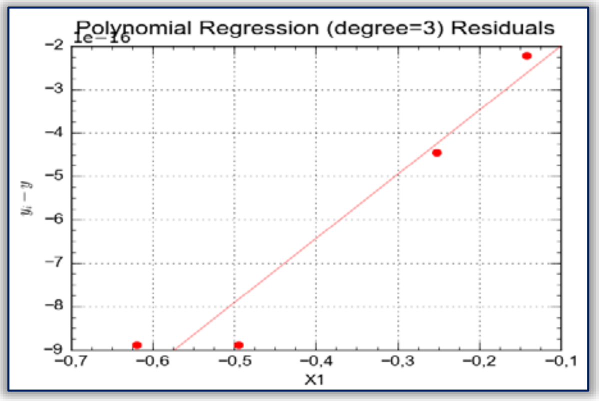

Figure 13. Residuals

Polynomial Regression that best fits to the measured values is:

$$F(x)= 1{,}736+ 1{,}923*x+ 4{,}616*x^2+ 4{,}273*x^3 \tag{13}$$

Both, the correlation coefficient(r) and the coefficient of determination (r^2) for this function are value of 1. The obtained values show that the function is suitable for the analysed situation. The graphical form of residual values also validates the model (figure 13).

A comparison between the founded function, based on the measured values is presented in the figure 14.

— **Effects of the depth of cut**

The obtained results, for the variations of the depth of cut are shown in Table 6 and plotted in figure 15.

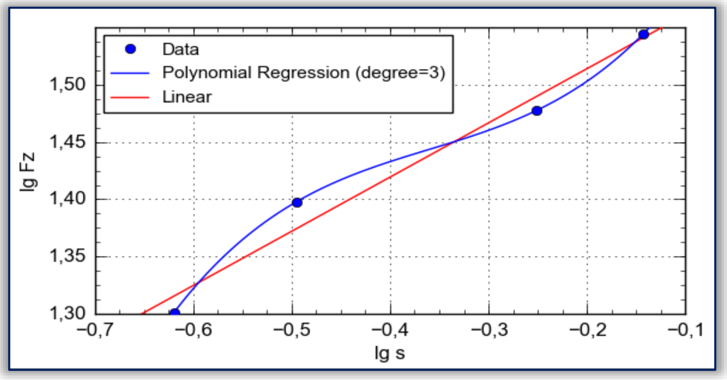

Figure 14. Comparison between linear and polynomial regression

Using relation (6), the slope of the line resulted by the variation of the depth of the cut can be calculated.

$$x_{F_z} = tg\alpha = \frac{\lg F_{t4} - \lg F_{t1}}{\lg t_4 - \lg t_1} = 1.229$$

Table 6. Obtained results for the variation of t parameter

S=0.32 mm/rot	lg t	Nr. div.	Fz (daN)	lg Fz
t1=0.5 mm	-0.30103	2	10	1
t2=1 mm	0	5	25	1.39794
T3=1.5 mm	0.176091	7	35	1.544068
t4=2 mm	0.30103	11	55	1.740363

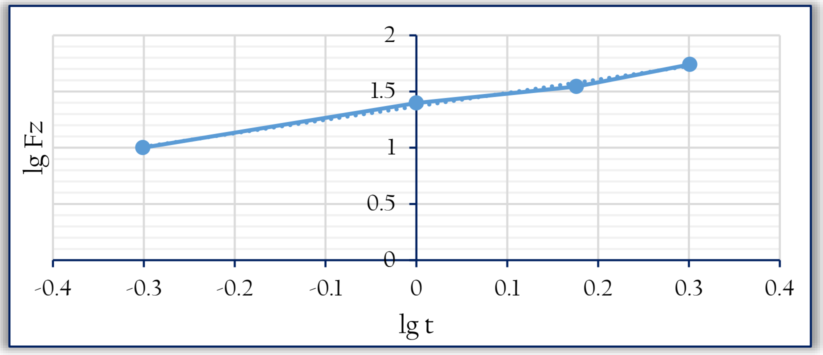

Figure 15. Evolution of the force according to depth of cut evolution

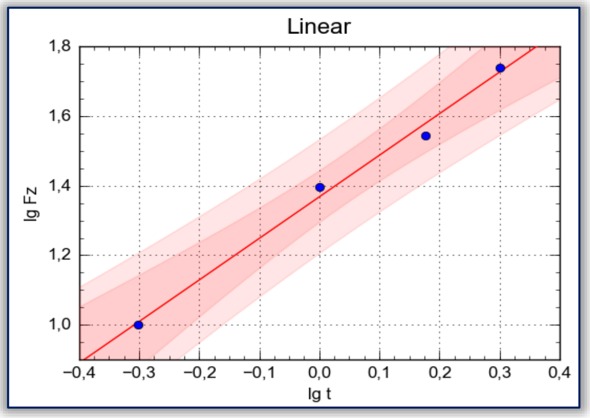

Figure 16. Linear regression.

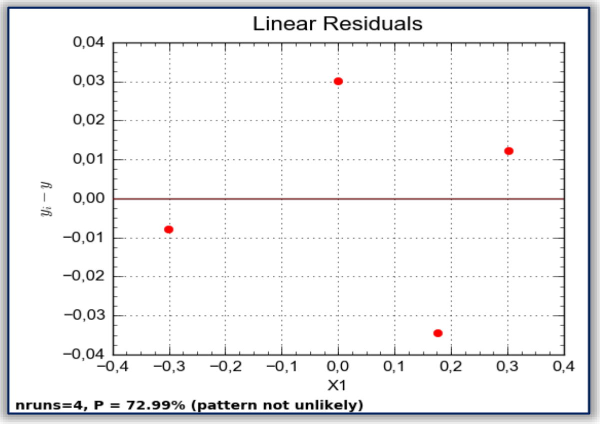

Figure 17. Residual values of the function

Linear regression that fits to the measured values is presented in relation (14) and its evolution can be seen in figure 16.

$$F(x) = 1{,}367 + 1{,}196 * x \quad (14)$$

For the considered linear regression (relation 12), in table 7, can be seen the parameters values.

Table 7. Parameter values of the obtained regression

	Value	Std. Err.	Range (95% confidence)
a	1,367921	0,017294	1,293510 to 1,442332
b	1,196251	0,075081	0,873204 to 1,519299

The correlation coefficient (r) is 0.9960 and the coefficient of determination (r^2) is 0.9922. The obtained values show that the function is suitable for the analysed situation. The graphical form of residual values also validates the model (figure 17).

In figure 18 is presented the polynomial regression, which fits best the obtained results.

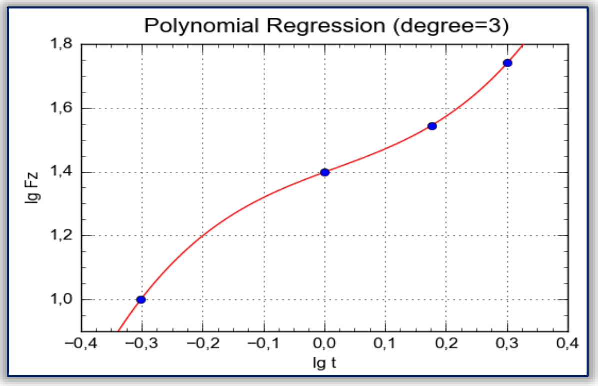

Figure 18. Polynomial regression

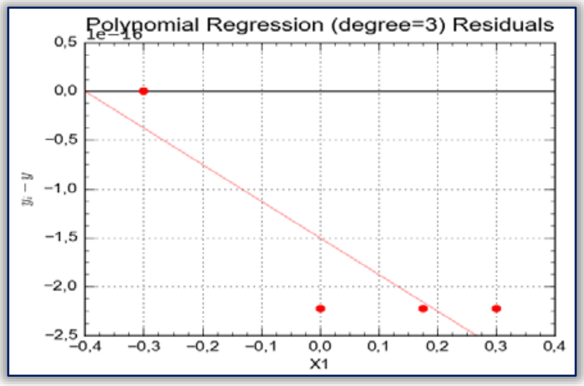

Figure 19. Residual values of the function

Polynomial Regression that best fits to the measured values is:

$$F(x)= 1{,}397+ 0{,}703*x -0{,}306*x^2+ 5{,}803*x^3 \quad (15)$$

The function is validated by the correlation coefficient(r) and the coefficient of determination (r^2), which are both the value 1, and also by the graphical representation of the residual values (Figure 19).

A comparison between the founded function, based on the measured values is presented in the figure below (figure 20).

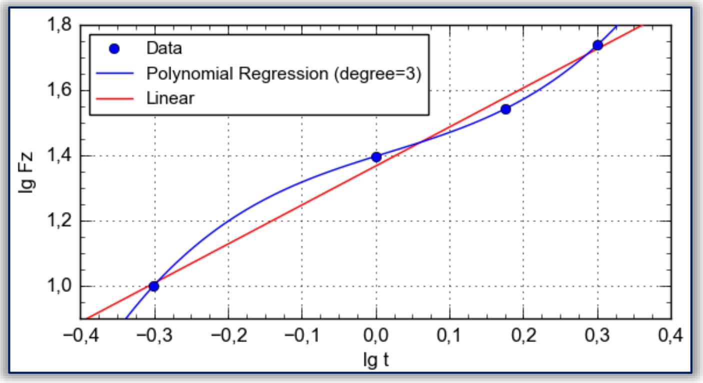

Figure 20. Comparison between linear and polynomial regression

4. CONCLUSIONS

Based on the experimental determination of the influence by the cutting parameters, depth of cut and feed, on the main component of the cutting force at turning, it can be drawn some conclusions.

The results highlighted that the influence of the depth of cut is most significant than the influence of the feed rate. The comparison between the values obtained at a 400 rot/min and the ones obtained at 800 rot/min shows the reduced influence of the cutting speed on the cutting forces.

Based on the measured values, it was made an analysis and identified the best fit equation for the data. The equations developed presents the correlation between the main component of the cutting forces and the evolution of the depth of cut and feed rate.

The results confirms the fact that, the cutting parameters have a significant influence on cutting forces, so an optimisation is necessarily in turning process.

Future research work will be directed towards identifying the influence of the cutting parameters on the tool and its durability.

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