EXPERIMENTAL INVESTIGATION OF CUTTING FORCE VARIATION ALONG THE TOOL CUTTING EDGE

Tamașag Ioan[1], Beșliu Irina[2], Amarandei Dumitru[3]

[1,2,3]*University Stefan cel Mare from Suceava, e-mail ioan_tamasag@yahoo.com*

Abstract: *Considerable scientific work was carried out along the years to understand the physics of the cutting process with the aim of a better control of these processes. This paper investigates the cutting force variation along the cutting edge in orthogonal cutting processes. This study can be helpful for a better prediction of tool wear in machining planning. Two sets of machining tests were carried out considering two different tool geometries.*

Keywords: *cutting force, turning, cutting edge*

1. Introduction

Cutting processes is the main manufacturing process used worldwide. Even if it is used since centuries, the understanding of all its specific phenomena it wasn't yet achieved. This is mostly because the complex physio-chemical aspects that these processes involve. The purpose of this study was to analyze the cutting forces fluctuations along the cutting edge.

According to the scientific literature, the cutting speed has a great influence on cutting forces levels. Based on this consideration/aspect, we can assume that even small variations of the cutting speed will result in a significant cutting forces variation.

Several scientific works have been carried out upon the forces of the cutting process on the cutting edge of the tool. Zhang and Guo [Zhang, 2015] modelled the cutting forces by discretizing the cutting edge and developed an approach for calculating the chip load corresponding to each discretized edge segment. Dorlin [Dorlin, 2016] developed a mechanistic model for the prediction of cutting forces during turning operations of titanium alloy Ti6Al4V, model that includes the effect of the clearance face contact radius. His model implies the effect of the clearance contact radius and the effect of the cutting edge lead angle which are determined independently via a direct identification method based on elementary cutting tests. Agic [Agic, 2016] studied the influence of cutting edge geometry on force build-up process in intermittent turning by conducting the geometrical analysis of rake angle and protection chamfer and developed a mathematical expression for the growth of the projected chip load area. Gradisek [Gradisek, 2004] developed expressions for semi-empirical mechanistic identification of specific cutting and edge force coefficients for a general helical end mill from milling tests at an arbitrary radial immersion.

Among the papers focused on the cutting forces on the cutting edge, the scientific literature doesn't provide many information on the force variation along the cutting edge according to cutting speed.

However, Belousov [Belousov, 1980] suggested that in local plane, the cutting speed varies with the depth of cut. Figure 1 represents a suggestive image of the turning process where the specific diameters are illustrated, Dmax is the diameter before the cutting process and Dmin is the diameter after the cutting process.

Figure 2 represents a close-up image of the machining area in which the cutting-edge length given by the cutting depth can be observed.

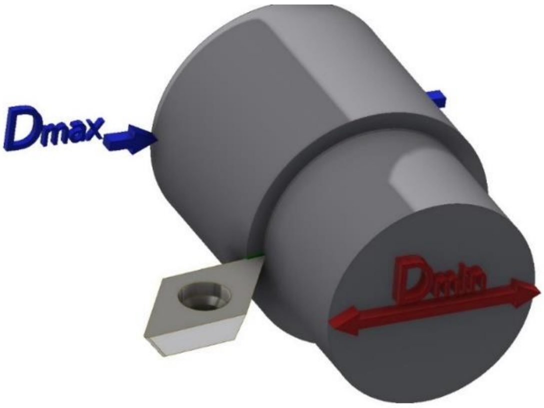

Figura. 1. *Turning process*

Figure 3 represents the analysis of the cutting zone where it can be seen that based on the depth of cut variation, the cutting speed varies. So basically, according to this figure, near the maximum diameter, the cutting speed will result bigger compared to the one corresponding the minimum diameter.

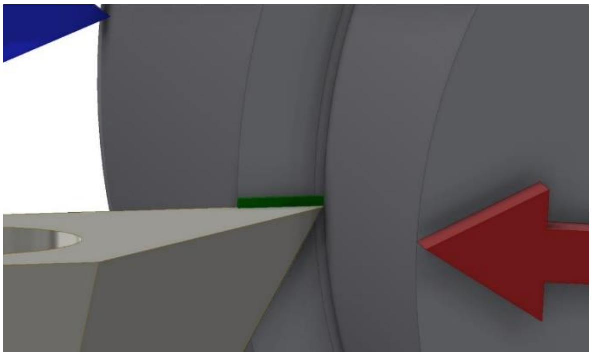

Figure 2. *The section of the cutting edge involved*

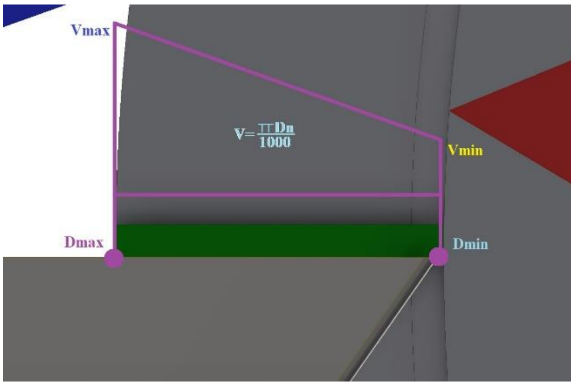

Figure 3. *Cutting speed variation with the depth of cut*

An example can be given when thinking about a general (hypothetical) turning process with a depth of cut of 2mm using a workpiece with diameter of Φ = 100 mm and a spindle speed of 1000 rev/min. The maximum diameter (Dmax) is Φ = 100 mm and the minimum diameter (Dmin) at the tool nose is Φ = 96 mm. According to equation (1), well known equation for the cutting speed determination, at the tool nose (Dmin), the cutting speed is V_0 = 301.44 m/min and at Dmax the cutting speed is V = 314 m/min.

$$V_c = \frac{\pi D n}{1000}, \quad (1)$$

where *D* is the diameter of the workpiece and *n* is the spindle speed

2. Experimental setup

In order to validate this hypothesis, a number of experiments was developed. The conditions of the experiments were as follows:

- There were used 3 probes having different diameters corresponding to the three different sections of the cutting edge considered, figures 4 and 5;
- The cutting depth was kept constant (the cutting tool was not moved);
- A number of 5 experiments for each cutting-edge section using were carried out in order to eliminate errors and used the values as mean values. That makes a total of 15 determinations;
- For each machining test set a different cutting insert was used;
- The nose radius was not included in the experiments.

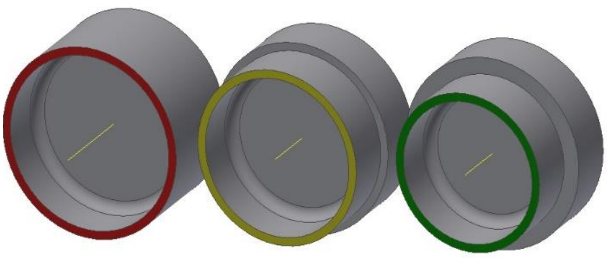

Figure.4. *Cutting tests specimen*

The workpiece material was C45 /AISI 1045.

The insert material was carbon carbide grade P20.

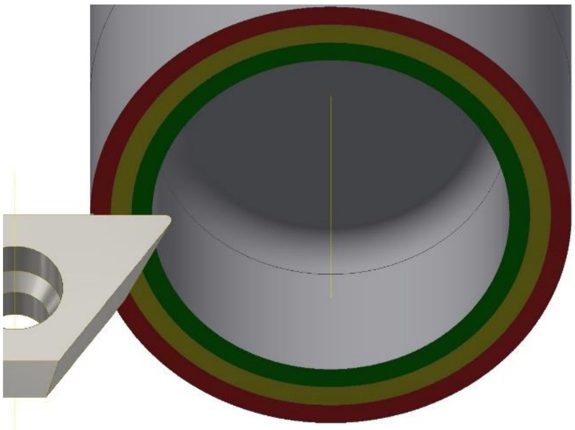

Figure 5. *The position of probes relative to the cutting edge*

The cutting conditions for the determination of forces on the tool edge are presented in table 1 and in table 2 is presented the cutting tool geometry.

Tabel 1 *Cutting conditions*

Set of experiments	n [rev/min]	f [mm/rev]	Vc [m/min]
1 D= 45mm	315	0,16	44.53
2 D= 42mm	315	0,16	41.56
3 D= 39mm	315	0,16	38.59

Tabel 2 *Tool geometry*

Cutting tool	k	γ	λ	α
1	45	-10	-10	10
2	90	-10	-10	10

3. Experimental results

The cutting tests were each repeated 5 times in order to observe the repeatability of the obtained results and accurate results. The obtained results for the cutting tool with the side cutting edge angle k = 45° are presented in table 3, and in table 4 there are the results obtained using the cutting tool with the side cutting edge angle k = 90°. Force components Fx, Fy and Fz were measured for each test with a specialized dynamometer Kistler 9257B.

Table 3. *Results obtained for the cutting tests carried out with the tool with the side cutting edge k = 45°*

Specimen	Force components	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Mean value
1	Fx	610.03	615.61	611.74	607.16	614.14	611.737
	Fy	643.852	643.55	631.06	634.75	634.04	637.451
	Fz	511.06	517.32	508.97	507.76	512.7	511.561
2	Fx	600.25	588.55	600.93	591.71	600.51	596.39
	Fy	607.437	587.90	599.55	592.25	604.84	598.395
	Fz	527.135	494.54	510.41	501.53	502.74	507.27
3	Fx	556.59	567.33	599.84	586.02	578.49	577.654
	Fy	561.677	571.31	608.97	593.93	577.19	582.615
	Fz	474.412	473.61	491.20	486.93	489.47	483.126

Table 4. *Results obtained for the cutting tests carried out with the tool with the side cutting edge k = 90°*

Specimen	Force components	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Mean value
1	Fx	926.33	940.1	934.1	924.57	944.24	933.87
	Fy	100.84	98.598	110.33	103.68	103.16	103.31
	Fz	535.64	530.94	528.96	522.35	533.6	530.29
2	Fx	916.56	904.97	897.4	923.97	918.46	912.27
	Fy	85.744	87.582	92.877	95.425	90.112	90.348
	Fz	532.21	527.34	527.17	528.69	527.44	528.5
3	Fx	908.7	881.25	878.29	887.42	883.56	887.848
	Fy	91.189	81.484	85.075	108.169	113.13	95.818
	Fz	511.58	508.342	505.81	508.424	507.01	508.234

The variation of the cutting forces on the tool cutting edge is illustrated in figure 6 and 7. Figure 6 presents the variation of the cutting forces obtained for the machining tests carried out with the cutting tool with the side cutting edge k = 45° and figure 7 presents the variation of the cutting forces obtained when the cutting tool with the side cutting edge k = 90° was used.

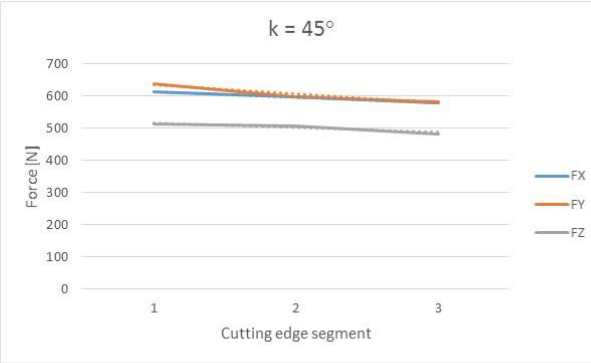

Figure 6. *Cutting forces variation along the cutting edges for the cutting tool with the side cutting edge k = 45°*

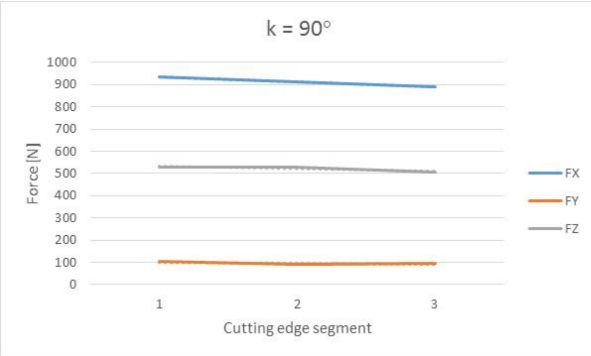

Figure 7 *Cutting forces variation along the cutting edge for the cutting tool with the side cutting edge k = 90°*

According to figures 7 and 8, for the tests carried out with the cutting tool with side cutting edge angles k = 45°, the cutting forces has the tendency to lower at the maximum diameter, and or the tool with side cutting edge angles k = 90° the forces are constant for Fy and Fz, but the Fx force has the tendencies to decrease. Nevertheless, even though the forces on the tool with side cutting edge angle k = 90° seems to be constant, at a lower level, the difference between the maximum diameter Dmax and the minimum diameter Dmin shows that the tendency is to decrease. We can assume that for both tools with different side cutting edge angles, the forces have higher values as we move away from the tool peak. This confirms the hypothesis that the forces vary with the cutting speed on the side cutting edge.

4. Conclusions

Cutting force variations can result in tool chatter, stiffness variations that can lead to tool damage and poor accuracy. That is why cutting force variation prediction can be a good prevention method. The purpose of this research work was to investigate the cutting forces (friction and plastic deformation forces) variation along the tool cutting edge. In order to illustrate this variation, we carried out tests by machining with different sections of the cutting edge. Based on the results obtained we can conclude that the cutting forces vary along the side of the edge of the cutting tool.

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