



GEOMETRIC ANALYSIS AND DESIGN OF FLAT FORM TOOLS

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Abstract: Form tool means a cutting tool which is appropriate manufacturing of workpieces having more complicated geometry. The contour of manufactured workpiece is manufactured by the tool profile. This cutting tool can be used in case of serial and quantity production. The advantageous of their usage are the lower turning time and the lower standard deviation of the workpiece sizes. The reached accuracy on the workpiece is independent from the qualification of the worker. The aim of this publication is the explanation of the geometric analysis and the design by analytical and constructional way. This type of tool is advantageously usable for manufacturing on CNC machine or conventional machine.

Keywords: flat form tool, design, analytic, complex geometry.

Geometrijska analiza i projektovanje profilnih alata. Profilni alat poznatiji kao alat za oblikovanje koji je pogodan za izradu radnih komada s složenijom geometrijom. Kontura izrađenog radnog komada izrađuje se prema profilu alata. Ovaj rezni alat može se koristiti u slučaju serijske i masovne proizvodnje. Prednosti njihove upotrebe su kraće vreme obrade i manja standardna devijacija veličina radnih komada. Postignuta tačnost na radnom komadu ne zavisi od iskustva radnika. Cilj ovog rada je objašnjenje geometrijske analize i dizajna na analitički i konstruktivni način. Ovaj tip alata ima prednost u upotrebi za proizvodnju na CNC ili konvencionalnim mašinama alatkama.

Ključne reči: profilni noževi, projektovanje, proračun, složena geometrija.

1. INTRODUCTION

There are two main groups according to the type of the manufacturing of the workpieces: radial cutting tools and axial cutting tools.

The flat form tool belongs to group of radial cutting tools so after the fixation of the tool into the fixture it can be movable into radial direction of the workpiece [1, 2].

The flat form tool (Figure 1) is mostly produced from high speed steel. Conditions of them are high tool life, manufacturing time and resharpening area. The main steps of the design process of a form tool are [3]:

- determination of the main sizes of the tool,
- calculation of the tool profile,
- creation of the technical drawing of the master gauge,
- creation of the technical drawing of the cutting tool.

The cylindrical workpiece is doing rotation motion (\vec{v}_c) while the tool is moving perpendicular for the axis of rotation of the workpiece (\vec{v}_f) (Figure 2).



Fig. 1. The application of the flat form tool [4]

The tool rake (γ_x) and the tool clearance (α_x) angles are continuously changing along the cutting depth. The sum of those angles are constant on each discrete points:

$$\gamma_{xv} = \gamma_x + \alpha_x = constant \quad (1)$$

Inverse correlation can be seen between the γ_x and the α_x angles from the lowest diameters to the highest diameters of the workpiece (Figure 2) [3]:

$$\alpha_{x1} < \alpha_{x2} < \alpha_{x3} \quad (2)$$

$$\gamma_{x1} > \gamma_{x2} > \gamma_{x3} \quad (3)$$

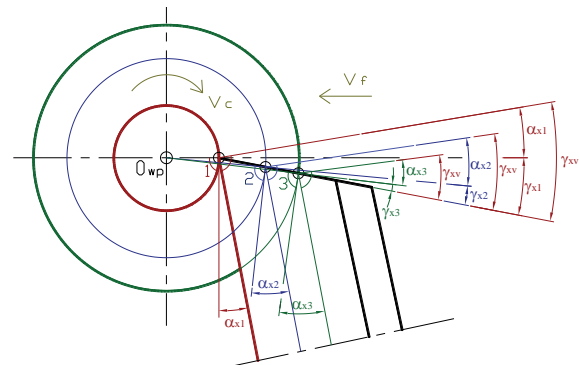


Fig. 2. The edge geometric analysis of the flat form tool

The tool rake (γ_x) is interpreted between the face surface of the tool and the connection line that contains the O_{wp} and the arbitrary selected point on the face surface of the tool.

The tool clearance (α_x) is interpreted between the parallel line of the flank surface of the tool and tangent line of the circle on the given arbitrary selected point on the face surface of the tool.

The creation of the angles on an arbitrary selected point on the face surface of the tool is the following:

1. select the arbitrary point along the face surface (for example the 2 point),
2. draw the circle which middle point is the O_{wp} and the radius is $\overline{O_{wp}2}$ distance,
3. joint the O_{wp} and 2 points. The angle between the face surface and the $\overline{O_{wp}2}$ line is the γ_{x2} tool rake on the 2 point,
4. draw the tangent line of the circle into the 2 point,
5. draw parallel line of the flank surface into the 2 point,
6. the angle between the tangent line and the parallel line is the α_{x2} tool clearance on the 2 point.

2. DETERMINATION OF THE MAIN SIZES OF THE FLAT FORM TOOL

We suppose the geometric establishment of the workpiece is given by the technical drawing. Firstly. the lowest (d_{min}) and the highest (d_{max}) diameters have to be

chosen. After that the highest profile depth can be calculated [2]:

$$g = \frac{d_{max} - d_{min}}{2} \quad (4)$$

The main sizes of the tool can be selected form Table 1 based on Figure 3.

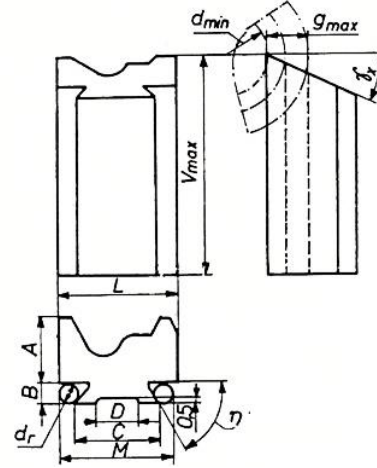


Fig. 3. The outside geometry of the tool [2]

g	The main sizes of the tool						The total size of the M clamping part			
	A	B	C	D	V	r	d_{r1}	M_1	d_{r2}	M_2
until 4	9	4	15	7	75	0.5	4	21.31	3	18.577
4...6	14	6	20	10	75	0.5	6	29.46	4	24
6...10	19	6	25	15	75	0.5	6	34.46	4	29
10...14	25	10	30	20	90	1	10	45.77	6	34.846
14...20	35	10	40	25	90	1	10	55.77	6	44.846
20...28	45	15	60	40	100	1	15	83.66	8	64.536

Table 1. The main sizes of the tool [2]

The recommendation of the construction tool rake (γ_{xu}) and the construction tool clearance (α_{xu}) can be chooseable on Table 2.

Material quality	Property		γ_{xu} [°]	α_{xu} [°]
	Ultimate strength [MN/m ²]	Hardness [HB]		
Steel	until 50	until 150	25	8...15
	50...80	150...235	20...25	
	80...100	235...290	12...20	
	100...120	290...350	8...12	
Cast iron		until 150	15	
		150...200	12	
		200...250	8	
Bronze and brass			0...5	
Copper and aluminium			20...25	

Table 2. The selection of the α_{xu} and γ_{xu} [2]

3. METHODS AND MATERIALS

3.1. Determination of the tool profile by constructional way

The outline drawings of the workpiece and the tool are not situated on the same plane (Figure 4).

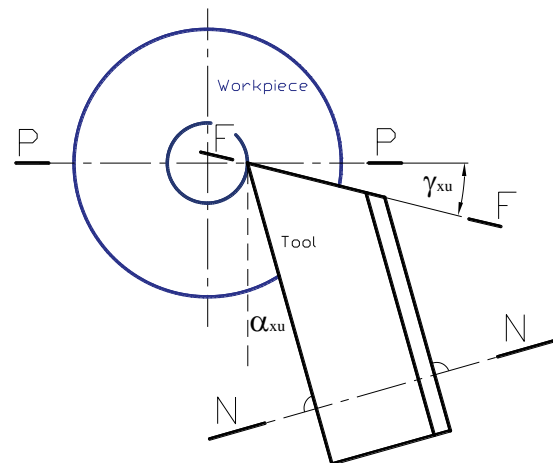


Fig. 4. The position of the planes

The P plane is the workpiece symmetric plane. The outline of the workpiece are found in this plane. The F plane is the face surface plane on the tool. The N plane is the tool normal plane on the tool where we have to determine the tool profile. After the selection of the α_{xu} and γ_{xu} and the outside geometry of the tool the position of the tool in comparison with the workpiece can be adjusted (Figure 4) [5, 6].

The construction process can be seen on Figure 5. After the adjustment of the tool and the workpiece the construction process is the following:

1. Given the geometry of the workpiece. The corner points (1, 2, 3, 4) have to be denoted.
2. Since the tool point is exactly on the symmetric plane of the workpiece that is why 1 and 1' points are the same.
3. The 1'' point is the tool point on the normal plane whose height is zero.
4. After the denotation of the 2 point, it has to be projected for the front view of the workpiece (Figure 6).

5. Creation of the r_2 radius:

$$r_2 = \overline{O_{wp}2} \quad (5)$$

6. Using of the r_2 radius the circle can be created. This circle will intersect the face surface on the 2' point (Figure 7). This point is on the face surface plane of the tool.
7. Parallely the flank surface the 2' point has to be projected into the normal plane.
8. The intersection of the projection line and the l_2 height will give the 2'' point on the normal plane of the tool.

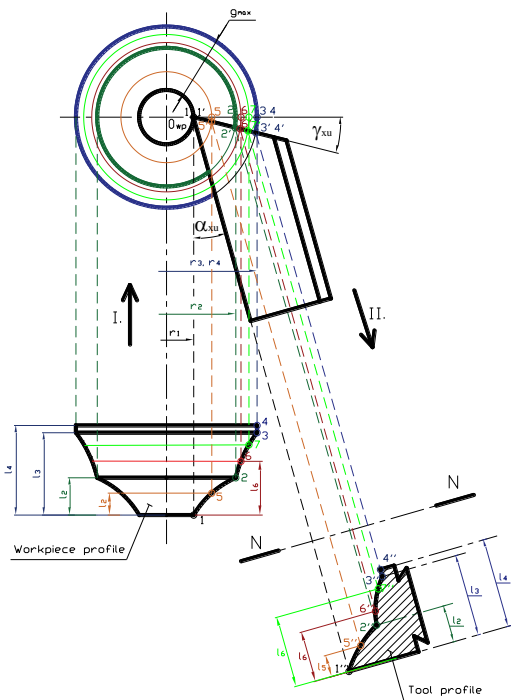


Fig. 5. The creation of the tool profile by constructional way

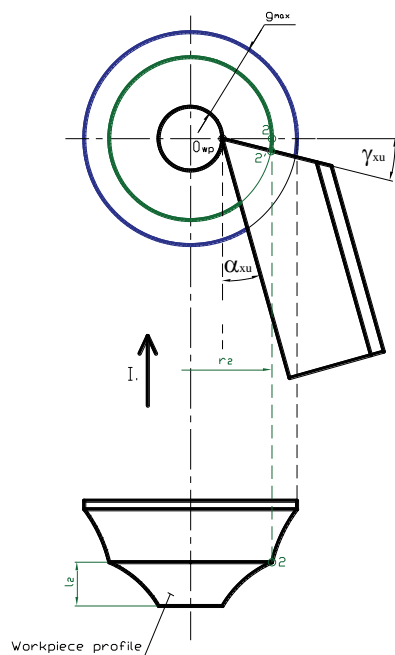


Fig. 6. Construction I

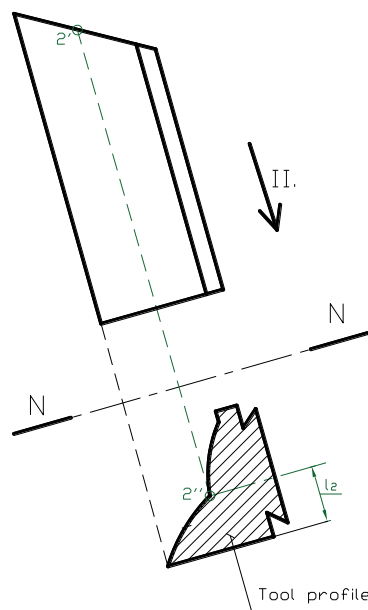


Fig. 7. Construction II

This process has to be repeated for all of the other points (Figure 5). Firstly, the positions of the corner points have to be determined on the normal plane. If there is arc on the workpiece the adoption of intermediary points are necessary. The more the number of the intermediary points, the more accurate the received arc on the normal plane of the tool (Figure 5).

3.2. Determination of the tool profile by analytical way

Initially, the outline drawing of the workpiece is known on the P symmetric plane that is a body of revolution.

Firstly, the tool profile has to be determined on the F face surface plane. After that the tool profile has to be determined on the N tool normal plane [3].

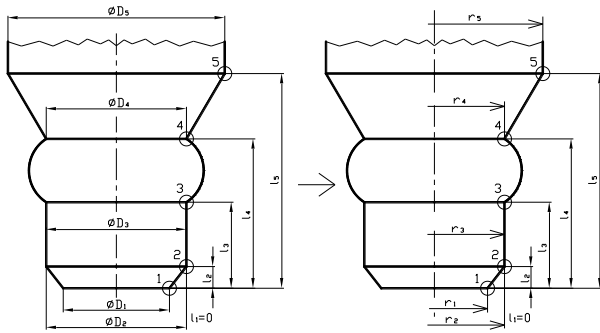


Fig. 8. Determination of the r_i and l_i value pairs

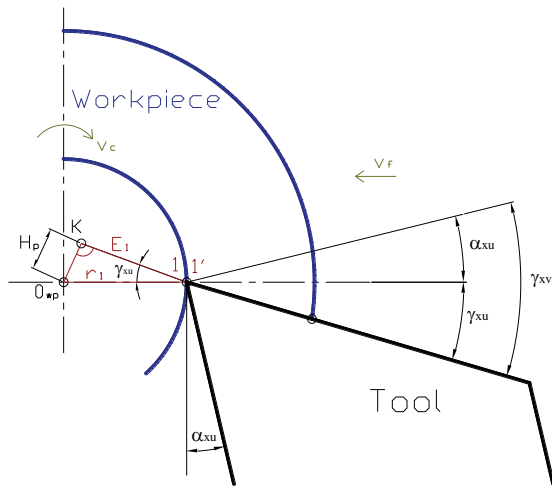


Fig. 9. Adjustment of the tool and the workpiece

Knowing of the geometric sizes of the workpiece the $r_1, r_2, r_3, \dots, r_i$ radiuses and the $l_1=0, l_2, l_3, \dots, l_i$ lengths have to be determined for every typical $1, 2, 3, \dots, i$ profile points. They are two coordinates (r_i, l_i) (Figure 8).

The lowest r radius point (1 point) is fitted as a tool point of the cutting tool.

Similarly to the constructional way in case of arc adoption a lot of points are needed because of the better profil accuracy of the cutting tool.

Starting of the 1 point and knowing of the γ_{xu} and α_{xu} angles the outline drawing of the tool can be created (Figure 9).

On the 1 point

$$\gamma_{xu} = \gamma_{x1} \quad (6)$$

$$\alpha_{xu} = \alpha_{x1} \quad (7)$$

The equations of the 1 point that is the tool point ($O_{wp}, K, 1$ triangle) (Figure 9) [2]:

$$H_p = r_1 \cdot \sin \gamma_{xu} \quad (8)$$

$$E_1 = r_1 \cdot \cos \gamma_{xu} \quad (9)$$

The H_p size and the $\gamma_{x1}, \gamma_{x2}, \gamma_{x3}, \dots, \gamma_{xi}$ tool rakes of the different points of the workpiece are needed for the calculation of the E and F sizes (Figure 10).

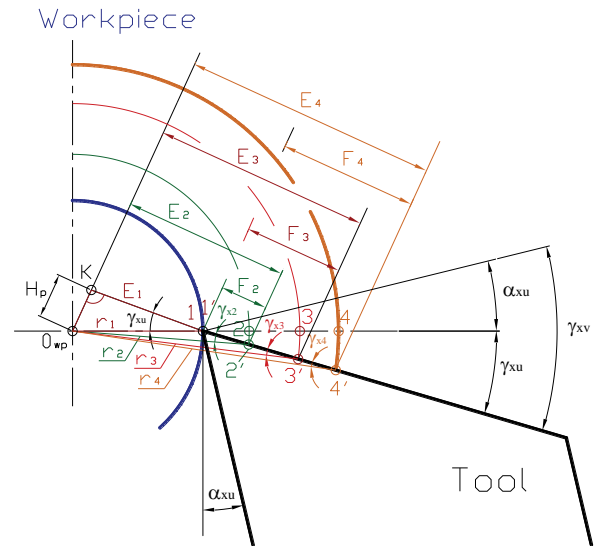


Fig. 10. Determination of the E and F sizes

The equations of the 2 point ($O_{wp}, K, 2'$ triangle) (Figure 10) are [3]

$$\sin \gamma_{x2} = \frac{H_p}{r_2} \quad (10)$$

$$E_2 = r_2 \cdot \cos \gamma_{x2} \quad (11)$$

$$F_2 = E_2 - E_1 \quad (12)$$

The equations of the 3 point ($O_{wp}, K, 3'$ triangle) (Figure 10) are [2]

$$\sin \gamma_{x3} = \frac{H_p}{r_3} \quad (13)$$

$$E_3 = r_3 \cdot \cos \gamma_{x3} \quad (14)$$

$$F_3 = E_3 - E_1 \quad (15)$$

The equations of an arbitrary i ' point of the workpiece are [2].

$$\sin \gamma_{xi} = \frac{H_p}{r_i} \quad (16)$$

$$E_i = r_i \cdot \cos \gamma_{xi} \quad (17)$$

$$F_i = E_i - E_1 \quad (18)$$

The F sizes show the position of the points on the face surface (F plane).

The $G_1, G_2, G_3, \dots, G_i$ sizes of the outline curve of the tool can be calculated from the $1-2'-2''$; $1-3'-3''$; $1-4'-4''$; ; $1-i'-i''$ triangles on the N normal plane. This plane is perpendicular for the flank surface (Figure 11).

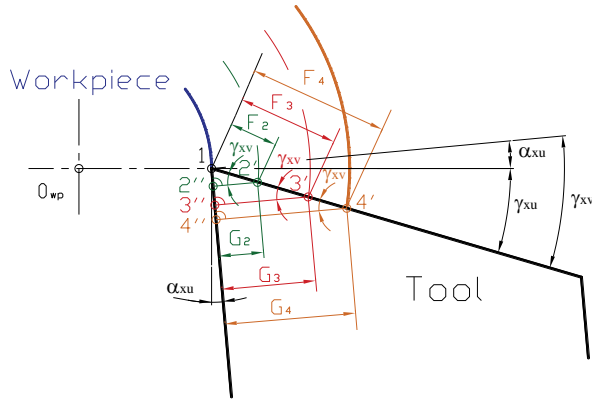


Fig. 11. Determination of the G sizes

The γ_{xv} construction tool rake is on all of the triangles that is a constant value. Based on those triangles the G sizes are [3]

$$G_1 = 0 \quad (19)$$

$$G_2 = F_2 \cdot \cos \gamma_{xv} \quad (20)$$

$$G_3 = F_3 \cdot \cos \gamma_{xv} \quad (21)$$

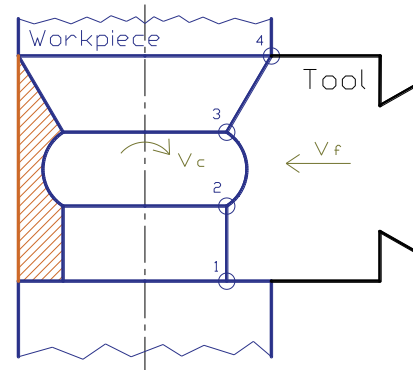
The equation of an arbitrary i point of the workpiece is [3]

$$G_i = F_i \cdot \cos \gamma_{xv} \quad (22)$$

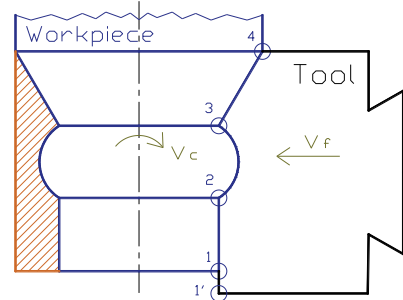
After this analytical calculation the (G_i, l_i) value pairs can be shown in a chart that is the profile of the tool on the N normal plane.

3.3. Determination of the outside section of the cutting edge

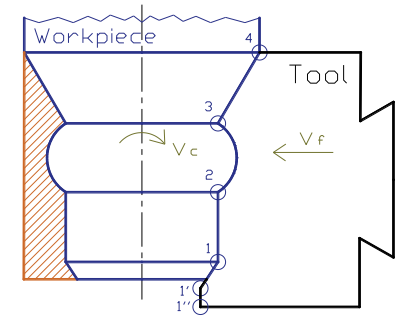
Different cases of the outline drawing of the workpiece are shown on Figure 12. The separated material is hatched.



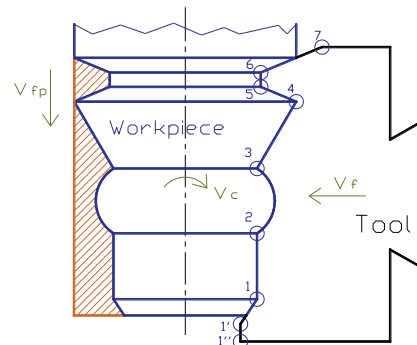
a) total edge length = formed length



b) total edge length > formed length



c) total edge length > formed length



d) cut – off technology

Fig. 12. The correlation of the total edge length and the formed length

The total edge length of the tool and the formed length of the workpiece are the same on Figure 12.a. The cutting tool has not additional edge in this case [3].

The formed length is at the end of the workpiece that is lower than the total edge length of the tool on Figure 12.b. That is why the $1-2$ edge section has to be increased with $1 \dots 3 \text{ mm}$ until the $1'$ point on the tool [3].

A chamfer is at the begin of the workpiece on Figure 12.c. In this case two additional edge sections are used $I-I'$ and $I'-I''$ on the tool. The length of the $I'-I''$ section is selected for 2...3 mm [3].

The total edge length of the tool is higher than the formed length on Figure 12.d. After the manufacturing by the form tool the workpiece will be separated from the blank by cut-off technology. The formed length is at the end of the workpiece and we have a chamfer [3]. The manufacturing technology is the following:

1. Manufacturing by flat form tool.
2. Removal of the flat form tool.
3. Workpiece separation by a parting-off tool.
4. According to the \vec{v}_{fp} periodical feed speed of the workpiece, moving of the workpiece based on the total length of the workpiece.
5. Repetition of the process in the function of the number of the workpieces.

This strategy is feasible in case of serial production using of a long blank.

4. RESULTS

A sample tool design process can be shown in this chapter. The initial geometry of the workpiece is on Figure 13.

The outside tool parameters were selected from Table 1 and 2. The resolution for the r and l sizes on the workpiece can be seen on Figure 15. The calculated geometric parameters on the tool can be seen on Table 3. After the calculation the tool profile on the $G-l$ coordinate system can be seen on Figure 14. The results of the construction way can be seen on Figure 16.

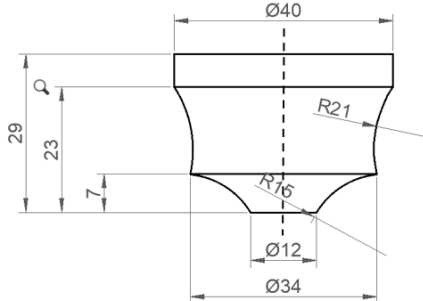


Fig. 13. The geometric establishment of the workpiece

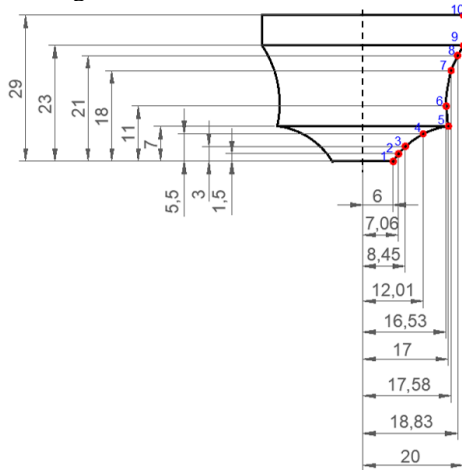


Fig. 14. The $r-l$ parameters on the workpiece

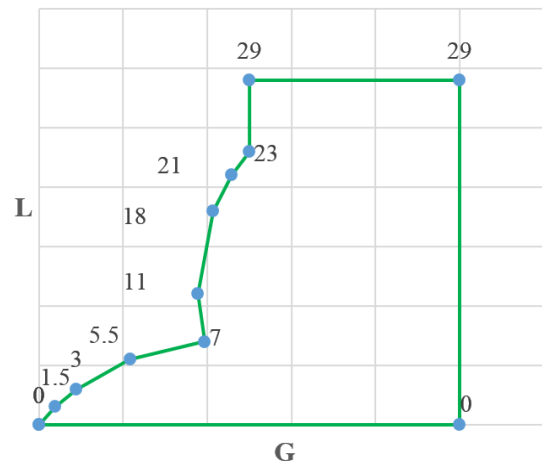


Fig. 15. The tool profile on the $G-l$ system

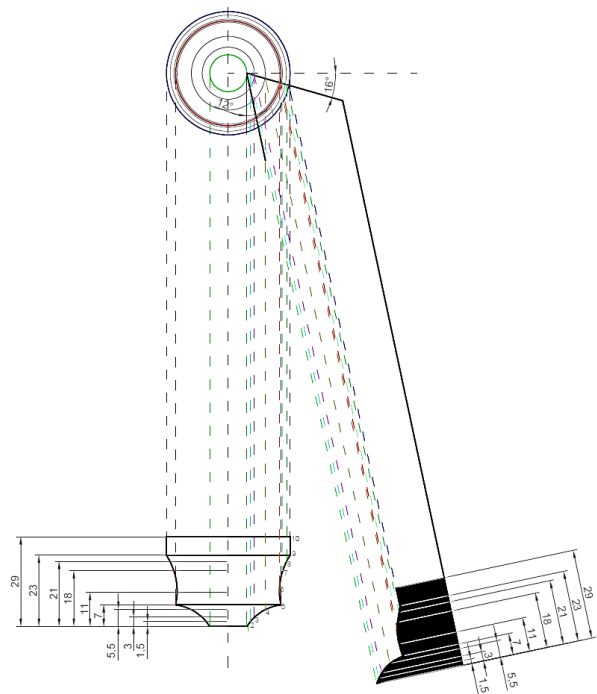


Fig. 16. Determination of the tool profile by constructional way

i	r [mm]	l [mm]	γ_{xi} [°]	E [mm]	F [mm]	G [mm]
1	6	0	0.279253	5.76757	0	0
2	7.06	1.5	0.23645	6.863561	1.095991	0.967702
3	8.45	3	0.19699	8.286577	2.519007	2.224151
4	12.01	5.5	0.138143	11.89559	6.128016	5.410717
5	17	7	0.097438	16.91936	11.15179	9.846449
6	16.53	11	0.100218	16.44706	10.67949	9.429429
7	17.58	18	0.094213	17.50204	11.73447	10.36092
8	18.83	21	0.087943	18.75723	12.98966	11.46919
9	20	23	0.082786	19.9315	14.16393	12.50601
10	20	29	0.082786	19.9315	14.16393	12.50601

Table 3. The calculated geometric parameters

Based on the geometry of the tool and the workpiece the CAD models can be generated. After that the models can be compiled for the inspection of the geometric accuracy of the tool (Figure 16 and 17).

The first step was to assign the material which was Steel for the finite element analysis (FEM analysis). Then, the force (1000 N) was applied to the cutting edge of the tool. The bottom of the tool was fixed and the mesh was by default. It can be observed that applying this force, the stress is not bigger than the allowable Yield limit value of the Steel (Figure 19, 20 and 21).

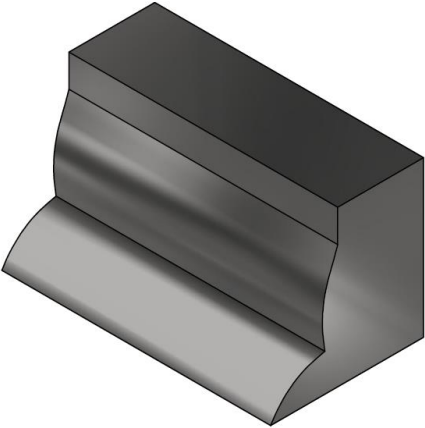


Fig. 17. The CAD model of the tool

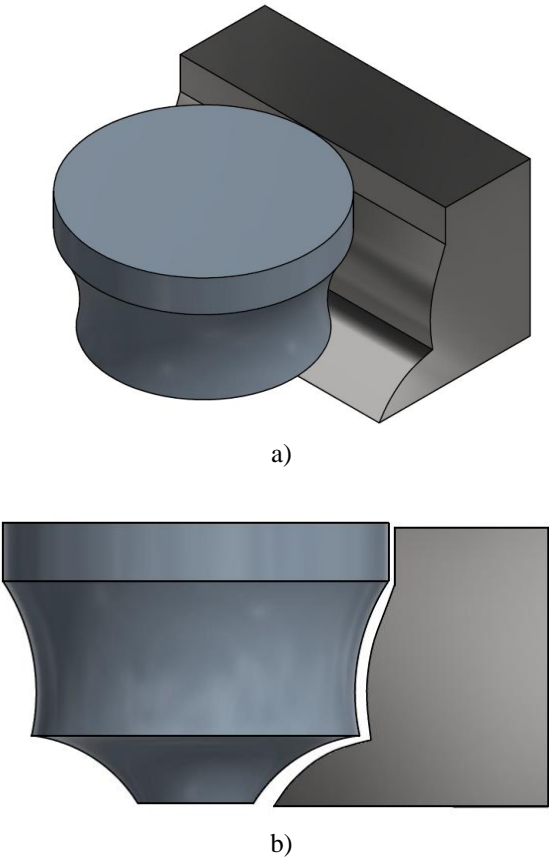


Fig. 18. The assembly of the tool and the workpiece

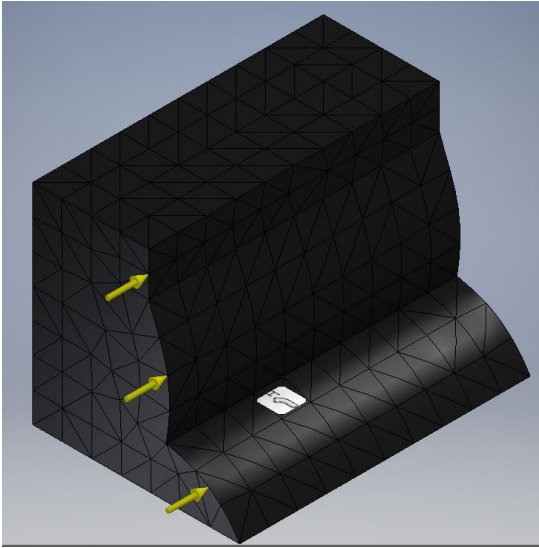


Fig. 19. The applied forces and mesh on the tool

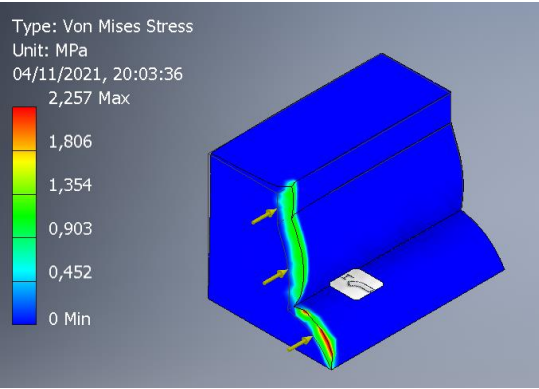


Fig. 20. Von Misses Stress Result

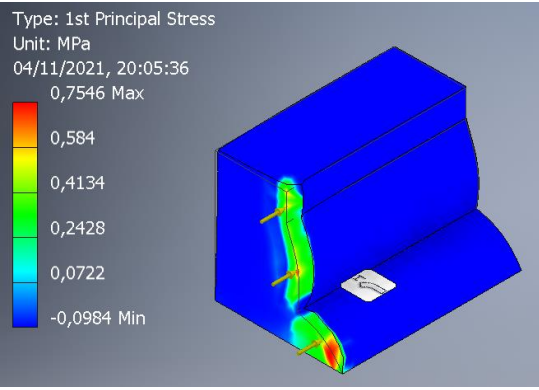


Fig. 21. Principal Stress Result

5. CONCLUSIONS

The scope of this publication is the explanation of the design process and the geometric analysis of the flat form tool by constructional and analytical way.

After the determination of the necessary formulas for the analytic calculation and the analysis of the constructional solution a concrete tool design process was introduced.

The assembly of the CAD models are recommended to inspect the correct geometric design of the tool.

FEM analysis is also recommended to analyse the load capacity of the cutting edge of the tool. The determination of the applied cutting force has to be happened based on the technological calculations.

6. ACKNOWLEDGEMENT

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8. INFORMATION

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