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Geometric analysis and design of circular form tools

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Abstract. Supposing serial or quantity production of cylindrical workpieces having complex geometry the application of circular form tool is applicable. This type of cutting tool has complex geometry as a consequence the geometric and the manufacturing design take a lot of time and cost but it is economical since the cutting process is quite fast. In addition, the tool usage is feasible on conventional or CNC controlled machines and the process is independent from the workers' facility. The tool profile is the conjugated pair of the workpiece profile. This tool geometry has high resharpening area that is advantageous comparing other form tools. The goal of this study is the manufacturing analysis and the geometric design of those tools. The geometric design process will be determined detailedly in constructional and mathematical way. After them a concrete tool generation process including CAD design will be shown.

1. Introduction

The circular form tool (Figure 1) belongs to the field of radial tools since the feed direction is perpendicular to the axle of the workpiece. This tool is advantageously made from high speed steel. Comparing to the flat form tool and the tangential tool it has the highest resharpening area due to the circular establishments. Practically it is resharpenable along the overall perimeter of the outside circle on the tool [1].

The executive ranking of the design process of this tool geometry is similar to the design process of the flat form tool [1, 6].



Figure 1. The geometric establishment [7] and the usage [8] of the circular form tool

The tool rake (γ_x) and the tool clearance (α_x) angles are gradually varying along the depth of cut. Starting from the 1 tool peak point the sum of these angles are decreasing if the 1 peak point is the deepest profile point of the tool (Figure 2):

$$\gamma_{xv} = \gamma_x + \alpha_x \tag{1}$$

$$\gamma_{xv1} > \gamma_{xv2} > \gamma_{xv3} > \gamma_{xv4} \tag{2}$$

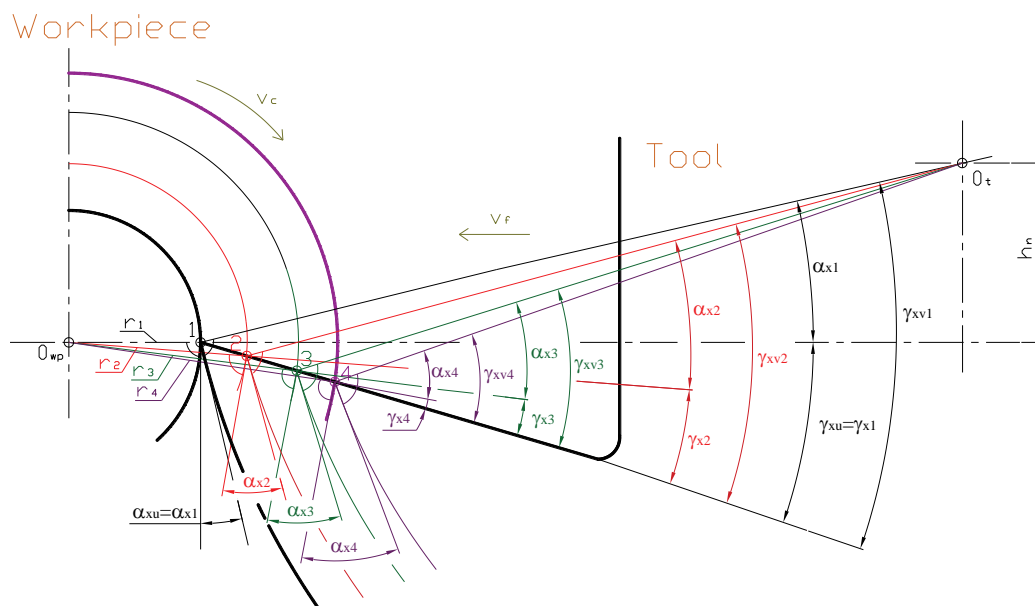


Figure 2. The edge geometric analysis of the circular form tool

Where the O_{wp} and the arbitrary selected point on the face surface of the tool are included (Figure 2) the tool rake (γ_x) is defined between the face surface of the tool and the common line [1].

The tool clearance (α_x) is defined between the tangent line of the auxiliary circle on the arbitrary selected point on the workpiece and the tangent line of the auxiliary circle on the same arbitrary selected point on the tool (Figure 2) [1].

The following steps (Figure 2) can be defined for the generation of the angles on an arbitrary selected point on the face surface of the tool:

1. choose (for example the 2 point) the arbitrary point along the face surface,
2. draw a circle whose middle point is the O_{wp} and the radius is $\overline{O_{wp}2}$ distance on the workpiece,
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 that belongs to the 2 point,
4. draw a circle whose middle point is the O_t and the radius is $\overline{O_t2}$ distance on the tool,
5. draw the tangent lines of the previous two circles on the 2 point,
6. the α_{x2} tool clearance means the angle between the two tangent lines is that belongs to the 2 point.

The O_{wp} and the O_t center points are not on the same height (Figure 2). The vertical distance between them is the h_n height. The $\overline{O_t1}$ distance is the external radius of the tool $R_t = D/2$ that is

selectable from the standard. Initially, $\alpha_{x1} = \alpha_{xu}$ where the α_{xu} is selectable from the standard. Based on Figure 2 the h_n height is

$$h_n = \frac{D}{2} \cdot \sin\alpha_{xu} \tag{3}$$

2. Selection of the main external sizes of the circular form tool

We assume the geometric shape of the workpiece is determined on the technical drawing. Firstly, we should select the lowest (d_{min}) and the highest (d_{max}) diameters on the workpiece geometry. The highest profile depth can be calculated after the selection of the diameters:

$$g = \frac{d_{max} - d_{min}}{2} \tag{4}$$

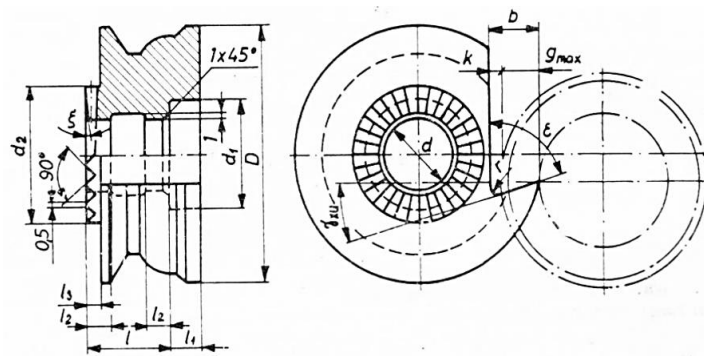


Figure 3. The standardized geometric parameters of the tool [1]

Table 1. The standardized external sizes of the tool without profile determination [1]

The highest profile depth, g_{max}	The main sizes of the circular form tool						The sizes of the collar	
	D	d (H8)	d ₁	b _{max}	k	r	d ₂	r ₂
until 4	30	10	16	7	3	1	0	0
4...6	40	13	20	10	3	1	20	3
6...8	50	16	25	12	4	1	26	3
8...10	60	16	25	14	4	2	32	3
10...12	70	22	34	17	5	2	35	4
12...15	80	22	34	20	5	2	40	4
15...18	90	22	34	23	5	2	45	5
18...21	100	27	40	26	5	2	50	5

The main standardized sizes of the tool are selectable form Table 1 based on Figure 3. Table 2 is necessary to recommend the construction tool rake (γ_{xu}) and the construction tool clearance (α_{xu}) in the function of the material type.

The l_1 size can be adopted in the function of the workpiece length [1]:

$$l_1 = \left(\frac{1}{4} \dots \frac{1}{2}\right) \cdot l \tag{5}$$

Table 2. The selection of the α_{xu} and γ_{xu} [1]

Material quality	Feature		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	

Knowing of the k and the g_{max} the b depth can be calculated [1]

$$b = g_{max} + k \tag{6}$$

The ε angle can be $\varepsilon=80^\circ$ in case of $\gamma_{xu} \leq 15^\circ$ tool rake or $\varepsilon=70^\circ$ in case of $15^\circ \leq \gamma_{xu} \leq 25^\circ$ tool rake [1].

3. Methods and material

3.1. The constructional solution of the generation of the tool profile

The outline profile contour of the workpiece and the tool are not laying on the same plane (Figure 4).

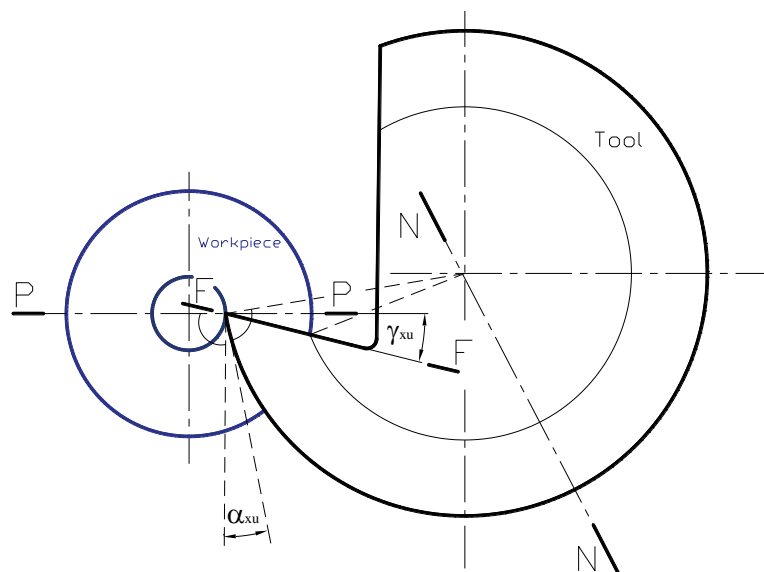


Figure 4. The position of the planes

The P plane that belongs to the workpiece is on the symmetric plane. On this plane the outline of the workpiece are available. The face surface plane on the tool is the F plane. The N plane is the tool normal plane for which we have to calculate the tool profile. The determined tool profile on the N plane is constant around the outside perimeter of the tool. The position of the tool compared to the workpiece can be set after the selection of α_{xu} and γ_{xu} and the outside geometry of the tool based on Figure 4.

The overall construction process (Figure 5) can be followable based on the following steps. After the setting of the elements the determination of the tool profile is:

1. Given the geometry of the workpiece on the technical drawing. The corner points (1, 2, 3, 4) have to be appointed on the P plane.
2. The tool peak point is defined exactly on the symmetric plane of the workpiece consequently 1 and 1' points are overlapped each other.

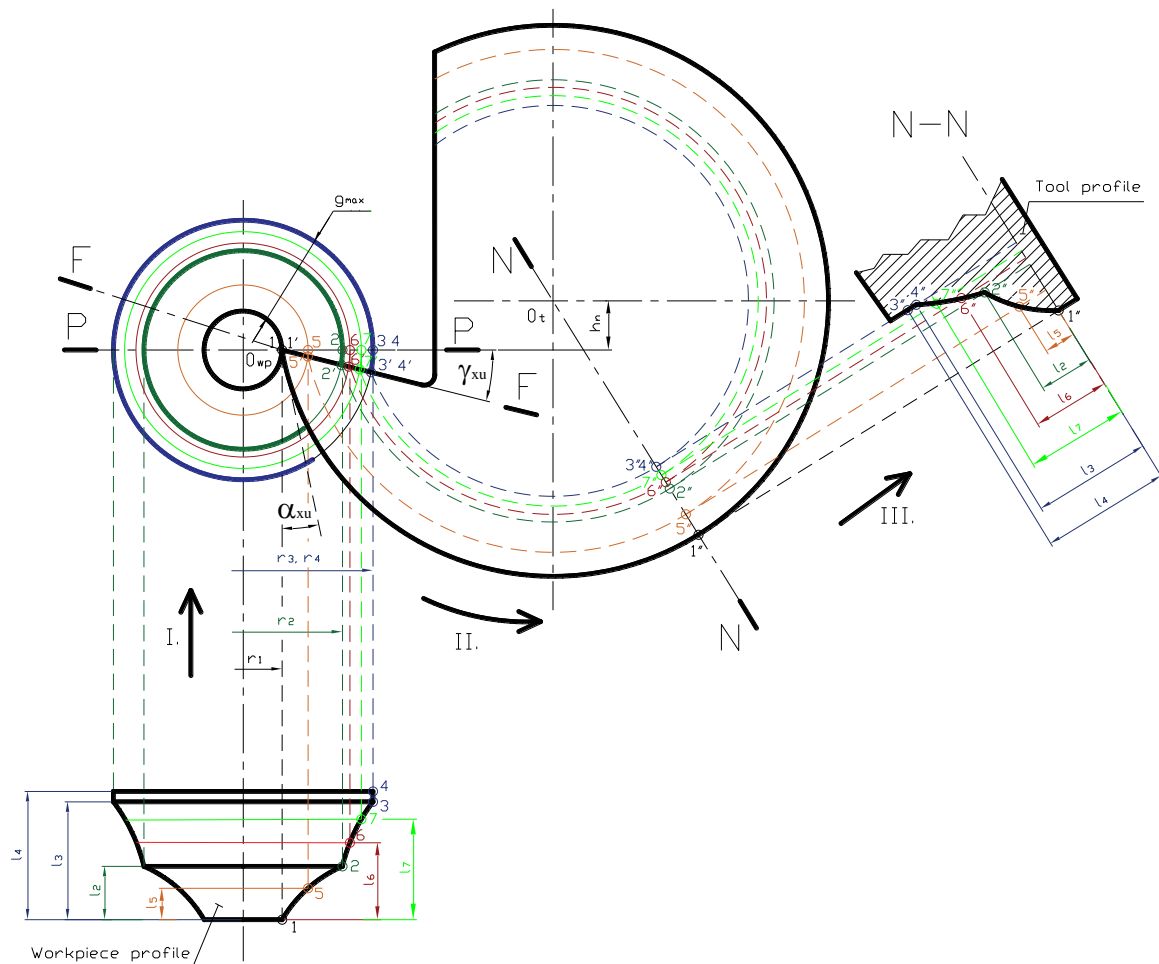


Figure 5. The generation of the tool profile with construction

3. The 1'' point is the tool peak point on the N normal plane whose height is zero on the base line but we have to consider approximately 2 mm extra length because of the avoidance of the peak on the profile.

4. The 2 point is projected (Figure 6) to the front view of the workpiece behind the appointment (*P* plane).
5. Calculation of the r_2 radius:

$$r_2 = \overline{O_{wp}2} \tag{7}$$

6. Using of the r_2 radius a circle can be created on the workpiece. The face surface will be intersected by this circle on the 2' point (Figure 6). The face surface plane (*F*) of the tool includes this point.
7. Creation of the R_2 radius:

$$R_2 = \overline{O_t2''} \tag{8}$$

8. Using of the R_2 radius another circle can be drawn on the tool. The *N* normal plane on the 2'' point (Figure 6) will be intersected by this circle. This point is on the normal plane (*N*) of the tool.

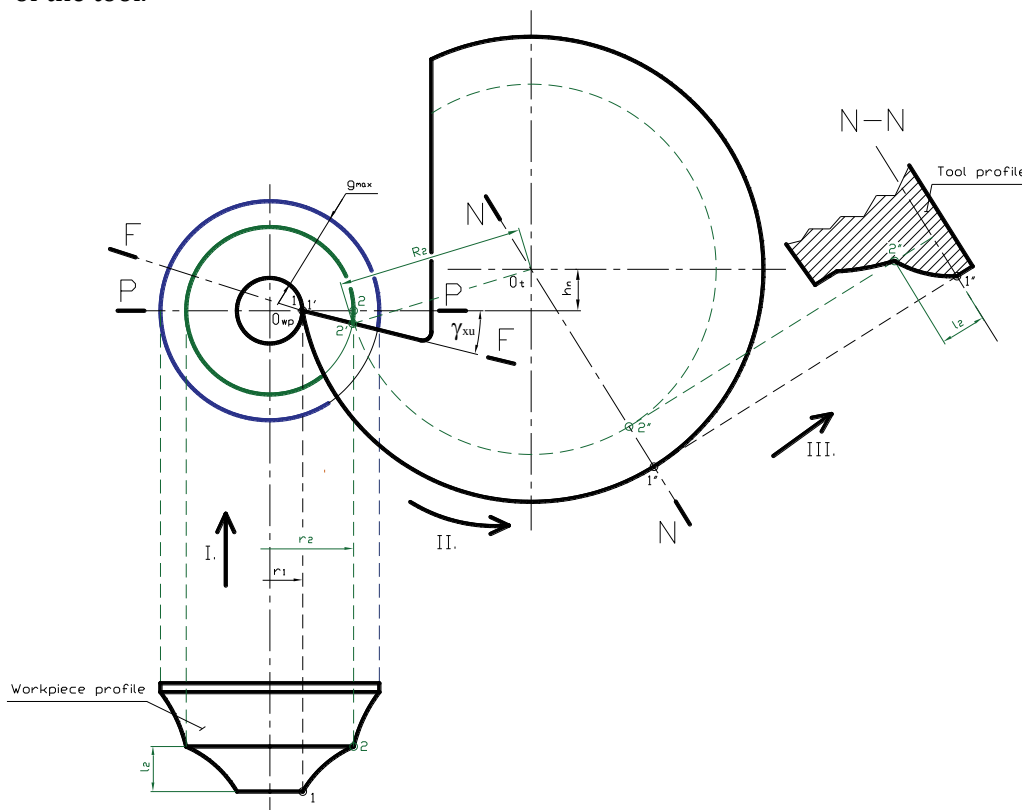


Figure 6. Construction II.

9. The 2'' point (Figure 6) will be the common point of the projection line and the l_2 height on the normal plane (*N*) of the tool.

This process has to be recuped for all of the other selected points (Figure 5). Initially, the positions of the corner points have to be appointed on the *N* normal plane. If there is arcs on the workpiece the selection of intermediary points on the curve is required. The more the number of

the selected points on the curve, the more punctual the generated arc on the N normal plane of the tool (Figure 5).

3.2. Analytical solution of the generation of the tool profile

Starting from the outline contour of the workpiece is the outline of a body of revolution on the P symmetric plane.

Initially, the tool profile has to be defined on the F face surface plane. After that this profile has to be transformed on the N tool normal plane [1].

Knowing of the geometric sizes of the workpiece every typical $1, 2, 3, \dots, i$ profile points have to be determined by the $r_1, r_2, r_3, \dots, r_i$ radiuses and the $l_1=0, l_2, l_3, \dots, l_i$ lengths after the partition. The (r_i, l_i) value pairs are the initial parameters for the analytical calculation.

The lowest r radius point (1 point) is on the tool point of the cutting tool. Similarly to the constructional process in case of arc adoption plenty of points are required due to the better profile precision of the cutting tool.

The outline contour of the tool can be created (Figure 7) starting of the 1 point and knowing of the γ_{xu} and α_{xu} angles and the D outside diameter.

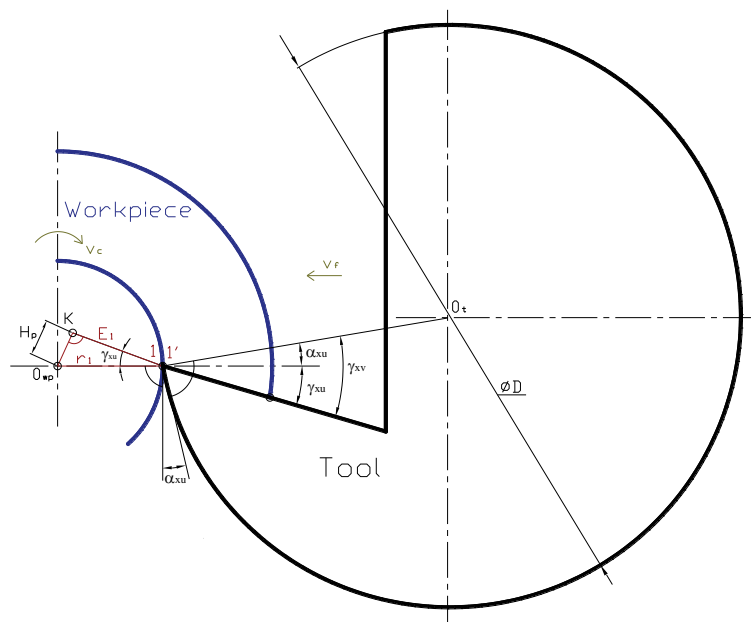


Figure 7. Adjustment of the tool and the workpiece

As we know on the 1 point [1]

$$\gamma_{xu} = \gamma_{x1} \tag{9}$$

$$\alpha_{xu} = \alpha_{x1} \tag{10}$$

Considering the $O_{wp}, K, 1$ triangle (Figure 8) the equations of the 1 point is the tool point [1]:

$$H_p = r_1 \cdot \sin \gamma_{xu} \tag{11}$$

$$E_1 = r_1 \cdot \cos \gamma_{xu} \tag{12}$$

The determination of the E_i and F_i sizes are given by the H_p size and the $r_1, r_2, r_3, \dots, r_i$ radiuses of the diverse points of the workpiece (Figure 8).

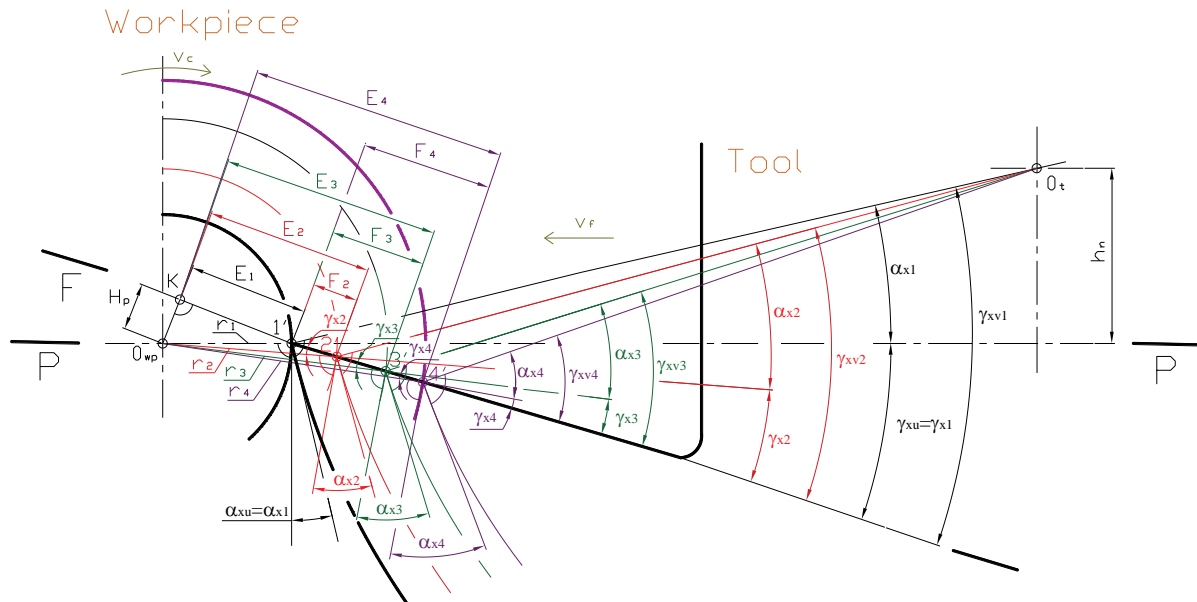


Figure 8. Determination of the E and F sizes

Considering the $O_{wp}, K, 2'$ triangle (Figure 8) the equations of the 2 point are

$$\sin \gamma_{x2} = \frac{H_p}{r_2} \tag{12}$$

$$E_2 = r_2 \cdot \cos \gamma_{x2} \tag{13}$$

$$F_2 = E_2 - E_1 \tag{14}$$

Similar to (12), (13) and (14) equations the parameters (γ, E, F) of other points on the workpiece can be determinable. The general equations of an arbitrary i point of the workpiece are [1]

$$\sin \gamma_{xi} = \frac{H_p}{r_i} \tag{15}$$

$$E_i = r_i \cdot \cos \gamma_{xi} \tag{16}$$

$$F_i = E_i - E_1 \tag{17}$$

The received F sizes give the position of the points ($1', 2', 3', 4'$) on the face surface (F plane) on the tool. A perpendicular line can be drawn from the O_t center point to the F face surface plane (Figure 9) to get the P point.

Based on $1', O_t, P$ triangle (Figure 10) the equations of the 1 point that is the same as the tool point are [1]

$$R_1 = \frac{D}{2} \tag{18}$$

$$\gamma_{xv1} = \gamma_{x1} + \alpha_{x1} \tag{19}$$

$$H_n = R_1 \cdot \sin \gamma_{xv1} \tag{20}$$

$$K_1 = R_1 \cdot \cos \gamma_{xv1} \tag{21}$$

$$G_1 = 0 \tag{22}$$

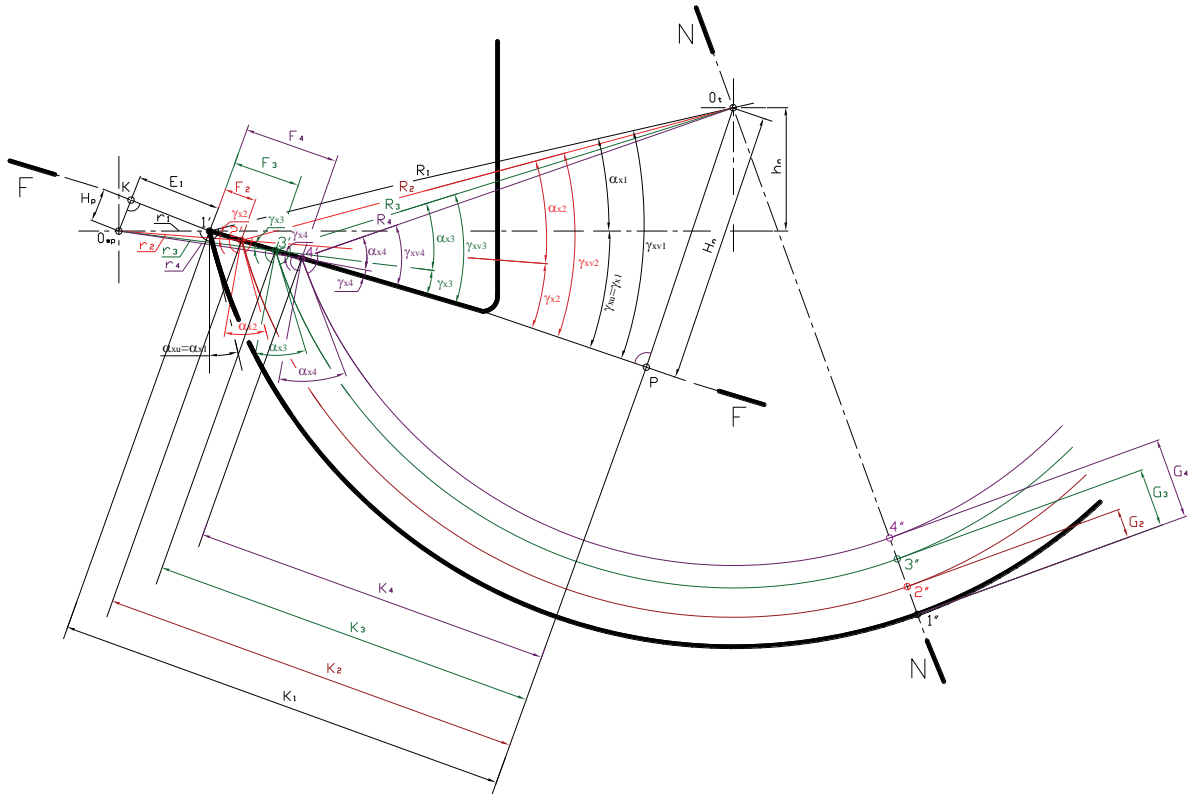


Figure 9. Determination of the G sizes

Based on the Z', O_i, P triangle (Figure 9) the equations of the 2 point can be calculated

$$K_2 = K_1 - F_2 \tag{23}$$

$$\tan \gamma_{xv2} = \frac{H_n}{K_2} \tag{24}$$

$$R_2 = \frac{K_2}{\cos \gamma_{xv2}} \tag{25}$$

$$G_2 = R_1 - R_2 \tag{26}$$

Similar to (23), (24), (25) and (26) equations the parameters (K, γ_{xv}, R, G) of other points on the workpiece can be determinable. The equations of an arbitrary i point of the workpiece can be determinable on the tool in general way [1]:

$$K_i = K_1 - F_i \tag{27}$$

$$\tan \gamma_{xvi} = \frac{H_n}{K_i} \tag{28}$$

$$R_i = \frac{K_i}{\cos \gamma_{xvi}} \tag{29}$$

$$G_i = R_1 - R_i \tag{30}$$

Behind the analytical calculation the (G_i, l_i) value pairs can be drawn on a chart. The received points have to be jointed. They are the profile of the tool on the N normal plane [1].

3.3. Generation of the external section of the cutting edge

There are distinct cases of the external contour of the workpiece as in case of flat form tool [6]. The four cases are the followings [1, 6]: total edge length = formed length, total edge length > formed length, total edge length < formed length and cut – off technology. The creation processes of the additional lengths of the tool are the same as the flat form tool has [1, 6].

4. Results

This chapter shows a tool design process. The outside geometry of the workpiece can be seen on Figure 10.

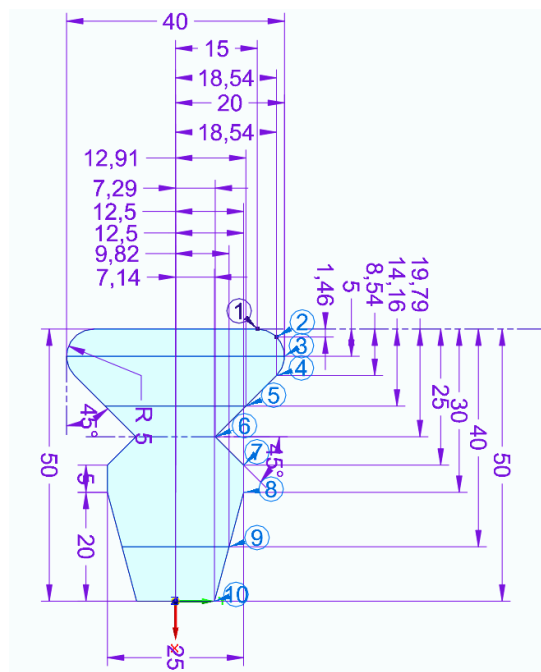


Figure 10. The initial sizes and the geometry of the workpiece

The selected tool sizes are $D=80$ mm, $d=22$ mm, $d_1=34$ mm, $b_{max}=20$ mm, $k=5$ mm, $r=2$ mm (Figure 3, Table 1).

The calculated results can be seen on Table 3. The received $G-l$ coordinates of the tool profile are on Figure 12. The generated geometric parameters are inspected by constructional way too (Figure 11).

After the determination of the tool profile the CAD models of the tool and the workpiece can be created and matched (Figure 12 and 13). Finally, the tool can be manufacturable by additive technology using of metal powder or cutting technology and inserted into a manufacturing process [2-5].

Table 3. The calculated geometric data of the tool

i	r [mm]	l [mm]	γ_{xi} [°]	E_i [mm]	F_i [mm]	G_i [mm]
1	15	0	25.00	13.59	0	0.00
2	18.54	1.46	20.007	17.422	3.832	2.86
3	20	5	18.491	18.969	5.379	3.96
4	18.54	8.54	20.007	17.422	3.832	2.86
5	12.91	14.16	29.427	11.246	-2.344	-1.82
6	7.29	19.79	60.453	3.598	-9.992	-8.09
7	12.5	25	30.493	10.773	-2.817	-2.20
8	12.5	30	30.493	10.773	-2.817	-2.20
9	9.82	40	40.233	7.499	-6.091	-4.84
10	7.14	50	62.649	3.284	-10.306	-8.35

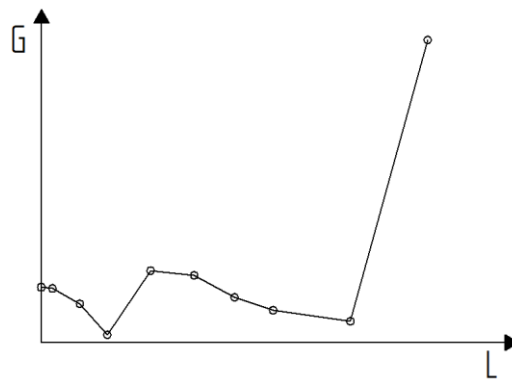


Figure 11. The profile contour of the tool on the G-l system

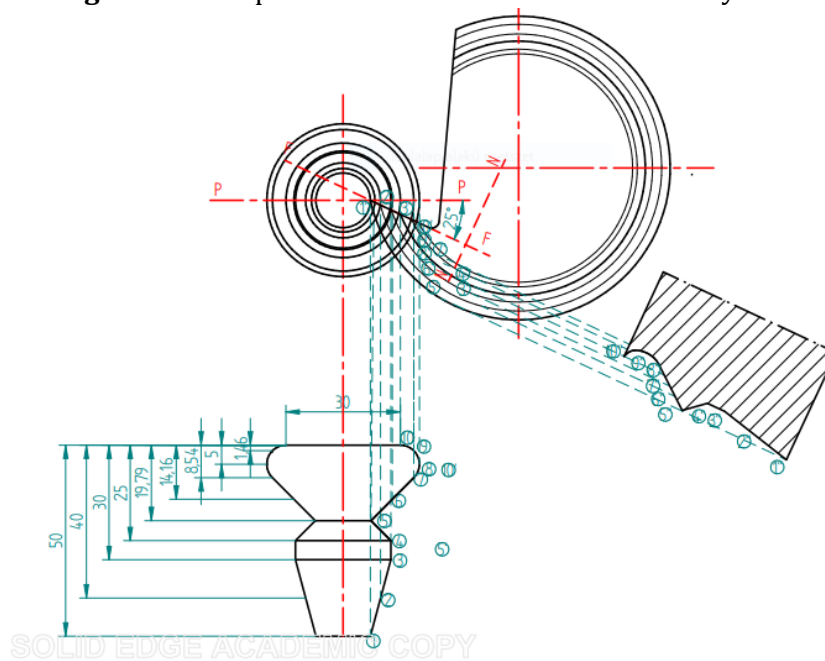


Figure 12. The constructional solution of the tool shape

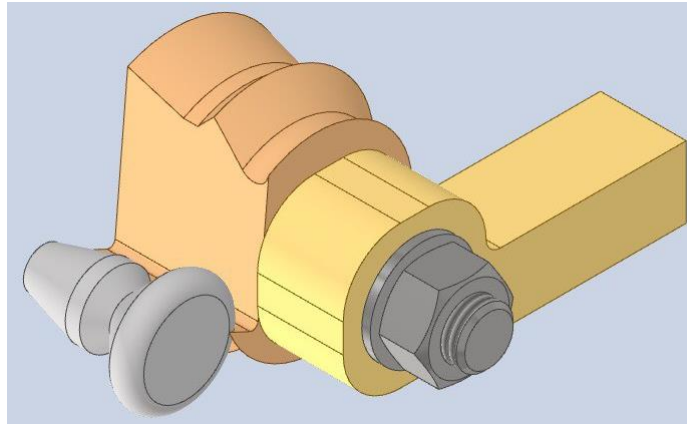


Figure 13. The compilation of the tool and the workpiece

5. Conclusion

The circular form tool is a unique cutting tool whose has individual tool profile considering the special profile of the workpiece. The application of this tool can improve the labour productivity and give better profit to a manufacturing company in case of serial or quantity production. Another advantage is the high resharpening area compared to the flat form tool or the tangential form tool.

A tool geometric analysis was shown in this work that is mandatory for the tool design. The total tool design process was detailedly determined by constructional and analytical ways. This work can be interesting for farther researches, the industry and inquiring engineers who wants to develop their skills in the field of tool design.

After the knowledge of the tool design process a real cutting tool was designed as a sample. After the geometric design and CAD modelling finite element analysis can be done. Finally, the tool is manufactured by additive technology or cutting technology.

References

- [1] E. Gorski, "Alakos megmunkáló szerszámok, Kések, Üregelőtüskék, Marók", Műszaki Könyvkiadó, Budapest, 1976, ISBN 963 10 1182 8
- [2] F. Klocke. "Manufacturing Processes I", Cutting, RWTH Edition, RWTH Aachen University, p. 524, ISBN 978-3-642-11978-1
- [3] J. T. Black, R. A. Kohser. "Materials and Processes in Manufacturing", Tenth Edition, United States of Amerika, p. 1033, ISBN 978-0470-05512-0
- [4] R. Golebski, P. Sikora, A. Gnatowski. "The use of new technology to improve the quality of production on a cnc machine tool", CzOTO 2019, volume 1, issue 1, pp. 583-590
- [5] N. Cofaru, I. I. Cofaru, R. Petruse, M. Rackov. "Parametrised Design of a Cutting Device Used for High Tibial Osteotomy", MATEC Web of Conferences 299(1):03011, DOI:10.1051/mateconf/201929903011
- [6] S. Bodzás. "Geometric analysis and design of flat form tools", Journal of Production Engineering 26 : 1 pp. 1-8. , 8 p., 2023
- [7] <https://www.indiamart.com/proddetail/circular-form-tool-11669258497.html> [download: 01. 01. 2024.]
- [8] <http://www.frets.com/HomeShopTech/Projects/LatheIndexRing/latheindexring.html> [download: 01. 01. 2024.]