3D MODELLING OF CYLINDRICAL CUTTING TOOL GEOMETRY WITH HELICAL TEETH

IOSIF DUMITRESCU[1], SORIN MIHĂILESCU[2], VILHEM ITU[3]

Abstract: In order to improve machining methods, quality tools used in industrial processing is particularly important. Cutter bits are the largest variety of constructive-functional solutions, many of which are of very special features in terms of computation and construction.

The 3D modelling of cylindrical cutters with helical teeth to emphasize constructive elements can easily see cutting edges and can analyze in detail the possibilities for sharpening and regrinding of the active parts. Using these modelling methods provides a considerable reduction in the time required to produce a prototype saving materials and resources is also an effective method of economically achieving a competitive cost price.

The paper presents possibilities for 3D model to calculate how positioning slitting tool to work piece adjustment and calculation of the router.

Keywords: 3D modelling; cutting tool; calculation

1. INTRODUCTION

Cutters are rotary splitting tools provided with one or several teeth; they do the main rotation movement, and the advance movement can be achieved by the part or by the cutter. Considering that they are slitting tools of the larger constructive-functional variety, many of those have special characteristics as far as calculus and design are concerned. In order to define the geometric parameters of the cutter, a general case is used, the cylindrical-frontal cutters, with front teeth an helical bits seated on the cylindrical side, the front bits actually being a prolongation of the helical teeth.

In the cylindrical-frontal cutter shown in figure 1, there are: 1 – helical teeth; 2 – helical grooves to include and remove chips; 3 – side of the helical teeth clearing the way; 4 – setting side of the helical teeth; 5 – helical edge; 6 – frontal teeth, a continuation of the helical teeth; 7 – frontal grooves for chips; 8 – main frontal edges;

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9 – secondary frontal edges; 10 – auxiliary frontal edges; 11, 12 – tips of the frontal teeth.

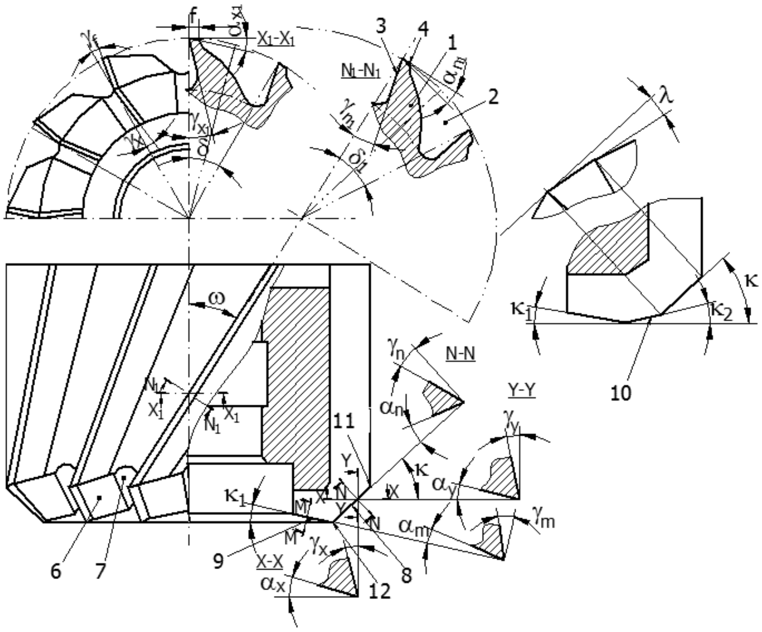


Fig. 1. Geometry of milling cutter

The angles of the slitting; part, for helical on the cylindrical surface, are: ω – angle of helical grooves; γ_{n1} – normal angle to clear the way; α_{n1} – normal setting angle; γ_{x1} – frontal angle to clear the way; α_{x1} –frontal setting angle.

The angles of the splitting part, for frontal teeth, are: κ – main attack angle; κ_1 – secondary attack angle; κ_2 – attack angle of the of the auxiliary edge; α_n – normal setting angle; γ_n – normal angle to clear the way; α_m – normal setting angle for secondary edge; γ_m – angle to clear the way for secondary edge; α_x – setting angle in $X – X$ radial plane; γ_x – angle to clear the way in $X – X$ radial plane; α_y – setting angle in $X – Y$ tangential plane; γ_y – angle to clear the way in $Y – Y$ tangential plane;

Between the angles measured in $X – X$, $Y – Y$ and $N – N$ planes, there are the following linking relationships:

- for helical teeth:

$$\tan\alpha_{x1} = \tan\alpha_{n1}\cos\omega, \quad (1)$$

$$\tan\gamma_{n1} = \tan\gamma_{x1}\cos\omega \quad (2)$$

- for frontal teeth:

$$\tan\alpha_x = \frac{\tan\alpha_n}{\sin\kappa + \tan\alpha_n \tan\lambda\cos\kappa}, \quad (3)$$

$$\tan\gamma_n = \tan\gamma_x \sin\kappa + \tan\gamma_y \cos\kappa\ . \tag{4}$$

To reach an easy detachment of the chips, with low splitting forces and to reach an as good as possible abrasiveness of the cut surfaces, the edges should be provided with positive angles to clear the way, in the range of 8 - 16°.

The setting angle provides an easy entry of the edge into the material, without friction and great effort to the back of the tooth, in the range of 4 - 18°. The principal angle of attack is in the range of 30 - 90°, the secondary angle of attack is in the range of 0 - 8°, and the angle of attack of the passing edge, in the range of 25 - 45°.

The design shapes and the geometric parameters of the teeth of the cylindrical and cylindrical-frontal cutting tools are shown in figure 2. In practice, the following teeth shapes and grooves for chips are met:

a) tooth with triangular profile (STAS 579-76, ISO 2586 –cylindrical-frontal cutting tools);
b) tooth with trapeze profile (STAS 579-76, ISO 2586);
c) tooth with facet profile(STAS 579-76, ISO 2586);
d) tooth with curved profile (STAS 579-76, ISO 2586);
e) tooth with relieved profile (STAS 577/1-78, ISO 3855 – cutting tools, classification).

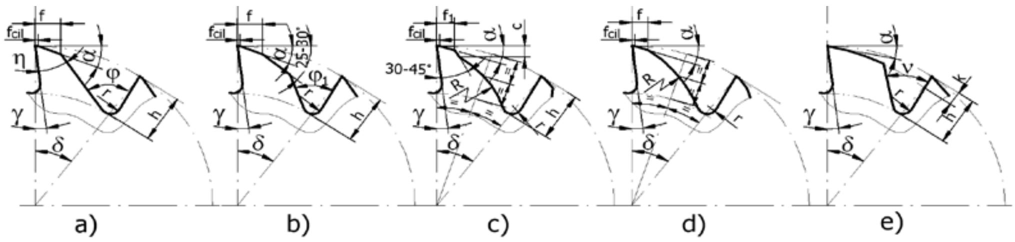


Fig. 2. Cutting tool teeth design shapes and geometrical parameters

The ideal shape of the back of the tooth from the point of view of mechanical resistance is the one with parabolic profile. The first four shapes are used for cutting tools with milled teeth, and the last for cutting tools profiled with relieved teeth

By their shapes, the teeth should meet the following conditions: high mechanical and thermal stability; easy execution, they should provide as many re-sharpening as possible; low fissuring tendency during thermal processing; large grooves with adequate profiles to include and easily remove chips.

The triangle profile tooth is the simplest concerning its design and technology, allowing however a small number of re-sharpening and has a lower resistance. It is used for cutting tools with dense teeth and cutters used for finishing.

The trapeze profile tooth has a good mechanical resistance and allows a great number of re-sharpening, being used for turning roughly and finishing.

Curved profile teeth with facet or prominent facet have higher mechanical resistance and rigidity and allows a great number of re-sharpening, being used with cutting tools with infrequent teeth.

The value of the inclination angle is established depending on the cutting tool type and its number of teeth, taking into consideration the fact that alongside with the increase of ω angle, an increase of the cutting tool durability is increased, due to the decrease of the unitary load and the increase of γ_x transversal angle for clearing the way. Based on these considerations, the following values are recommended for ω angle: for cylindrical cutting tools with dense teeth in the range of 25 - 35°; for cylindrical cutting tools with infrequent teeth , in the range of 30 - 60°; for disk shaped cutting tools with two or three edges , in the range of 15 - 25°.

In the case of cylindrical-frontal cutting tools, the size of the inclination angle should take consideration of the fact that this angle is in the same time γ_y longitudinal angle for clearing the way of the main frontal edge and cannot be greater than 25 - 30°, since the frontal edges come out excessively weakened in thermal-mechanical respect.

To determine the teeth' design elements the following formula is used:

- angle of triangular profile in normal plane,

$$\eta = \varphi - \delta_n - \gamma \text{, grad,} \tag{5}$$

where: φ is the groove angle and is in the range of 50°-110° out of 5° in 5° and in the range of 25 – 60° for the tooth with relieved profile; retrieved profile; δ_n – angular pitch in the cutting tool's normal plane is determined function of the angular pitch in frontal plane δ with the formula:

$$\delta = \frac{360}{Z},\ \delta_n = \arctan(\tan\delta\cos\omega)\text{, grad,} \tag{6}$$

where Z is the cutting tool's number of grooves.

Height h of the tooth can be approximated with the formulae:

- For triangular profile tooth $h = (0{,}5...0{,}6)\, p_n$;
- For trapeze and curved profile tooth $h = (0{,}3...0{,}4)\, p_n$, (7)

where p_n is the pitch in a normal section on the edge, which can be determined with the formula:

$$p_n = \sqrt{R_f^2 + R_e^2 - 2\, R_f\, R_e \cos\delta_n}\text{, mm,} \tag{8}$$

where: R_f is the cutting tool's radius, in mm; R_e – radius of the point on the ellipse corresponding to the normal angular pitch that is determined with the formula:

$$R_e = \frac{R_f}{\sqrt{1-(\sin\omega)^2 (\sin\delta_n)^2}}, \text{ mm.} \tag{9}$$

The radius at the chips groove bottom r is selected in the range of 0,8 – 2 mm for triangular profile tooth and 2 – 3 mm for trapeze and curved profile tooth

The optimum width of the facets is: f_{cil} = 0,05 – 0,1 mm and f_1 = 0,8 – 2 mm.

The radius of the circle arc of the back of the curved profile tooth or of the tooth with prominent facet is given by the formula:

$$R = (0{,}3...0{,}45)\,D_f, \text{ mm.} \tag{10}$$

2. 3D MODELLING OF CYLINDRICAL CUTTING TOOLS

A 3D model of 100×125 STAS 578-76/Rp 3 cylindrical cutting tools with trapeze tooth in normal construction with the help of Solid Edge soft is performed. This has the following design characteristics: cutting tool diameter D_f = 100 mm; boring diameter d = 40 mm; cutting tool length L = 125 mm; boring support fillet length l_1 = 31 mm; wedge groove width b = 10 mm; depth of wedge groove t = 3,5 mm; radius of wedge groove r = 1,2 mm; number of teeth Z = 10; tooth height h = 11 mm; width of cylindrical facet f_{cil} = 1,5 mm; groove helix angle $\omega = 25^o$; angle of clearing the way $\gamma = 12\pm2^o$; setting angle $\alpha = 10\pm2^o$; groove angle $\varphi = 50^o$.

Based on the relationship (6), $\delta_n = 33{,}36°$ angular pitch has been determined, with the help of formula (9) R_e = 51,45 mm is determined, and with the formula (8), the pitch in normal plane was calculated on the helix of the tooth p_n = 29,15 mm. Knowing that by the intersection of the normal plane on the tooth helix with the cylindrical body of the cutting tooth, an eclipse with the small axis equal to the cutting tool diameter and the large axis equal to results $b = D_f/\cos\omega$ = 110,34 mm. With the help of these data the diagram of the transversal profile of the groove is done, in figure 3.a, in an inclined plane as to the axis of the cutting tool with the angle $\theta = 90 - \omega = 65°$.

Figure 4.a presents the calculus sheet of the directing curve of the cutting tool's helical groove, with the formulae:

$$\begin{aligned} x_i &= R\sin\varphi_i; \\ y_i &= R\cos\varphi_i; \\ z_i &= R\varphi_i \tan(\pi/2-\omega). \end{aligned} \quad \text{, mm,} \tag{11}$$

where φ_i is the rotation angle around the cutting tool axis, in rad.

Based on the calculation sheet in Fig. 4.a, the calculation sheet in Fig. 4.a has been generated, by ordination the coordinates of (x_i, y_i, z_i) points, allowing a generating curve to be drawn for the groove profile, shown in Fig. 3.b, with the help of the calculation tables, by *Curve by Table* control.

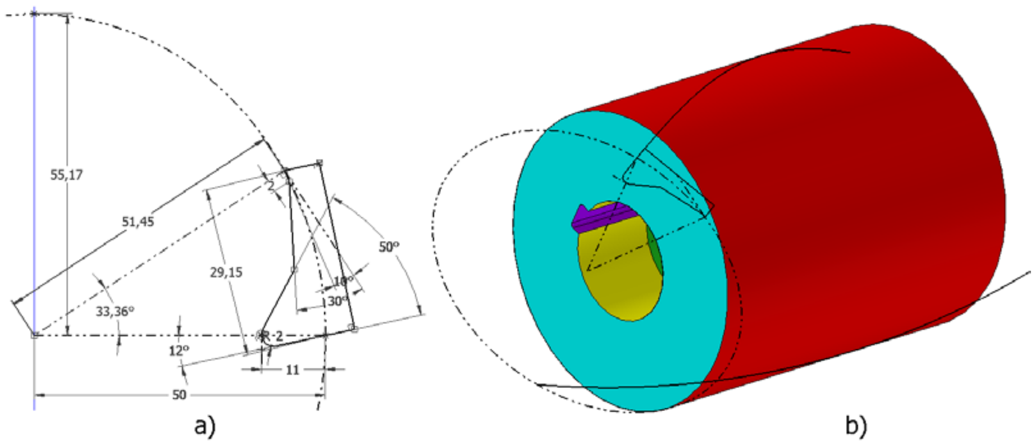


Fig. 3. Stages of carrying out the transversal section of its groove and directing curves

E3 f_x =50*B3*TAN(C3)

A	B	C	D	E	F
unghiul	**fi**	**teta**	**y**	**z**	**x**
fi de rot	**rad**	**rad**			
0	0	1,134464	-50	0	0
5	0,087266	1,134464	-49,8097	9,357177	-4,35779
10	0,174533	1,134464	-49,2404	18,71435	-8,68241
15	0,261799	1,134464	-48,2963	28,07153	-12,941
20	0,349066	1,134464	-46,9846	37,42871	-17,101
25	0,436332	1,134464	-45,3154	46,78588	-21,1309
30	0,523599	1,134464	-43,3013	56,14306	-25
35	0,610865	1,134464	-40,9576	65,50024	-28,6788
40	0,698132	1,134464	-38,3022	74,85741	-32,1394
45	0,785398	1,134464	-35,3553	84,21459	-35,3553
50	0,872665	1,134464	-32,1394	93,57177	-38,3022
55	0,959931	1,134464	-28,6788	102,9289	-40,9576
60	1,047198	1,134464	-25	112,2861	-43,3013
65	1,134464	1,134464	-21,1309	121,6433	-45,3154
70	1,22173	1,134464	-17,101	131,0005	-46,9846
75	1,308997	1,134464	-12,941	140,3576	-48,2963
80	1,396263	1,134464	-8,68241	149,7148	-49,2404
85	1,48353	1,134464	-4,35779	159,072	-49,8097

Foaie1 Foaie2 Foaie3

C1 f_x =Foaie2!E3

A	B	C
0	-50	0
-4,35779	-49,8097	9,357177
-8,68241	-49,2404	18,71435
-12,941	-48,2963	28,07153
-17,101	-46,9846	37,42871
-21,1309	-45,3154	46,78588
-25	-43,3013	56,14306
-28,6788	-40,9576	65,50024
-32,1394	-38,3022	74,85741
-35,3553	-35,3553	84,21459
-38,3022	-32,1394	93,57177
-40,9576	-28,6788	102,9289
-43,3013	-25	112,2861
-45,3154	-21,1309	121,6433
-46,9846	-17,101	131,0005
-48,2963	-12,941	140,3576

Foaie1 Foaie2 Foaie3

a) b)

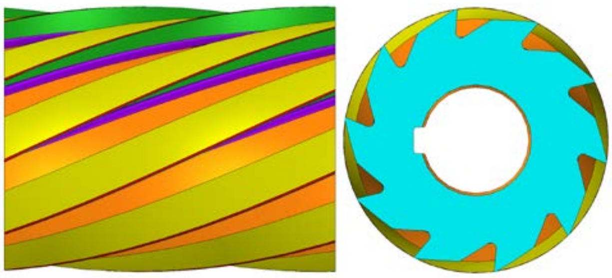
Fig. 4. Calculation of the helical groove profile of the cutting tool in Excel

With the help of the transversal section profile, Fig. 3.a, and the two directing helical curves, Fig. 3.b, a helical groove is generated with *Swept Cutout* control, and with *Pattern* control a multiplication of the groove in circular matrix on the cylindrical surface is performed, the chipping part of the cylindrical cutting tool with inclined teeth resulting, shown in Fig. 5.a. In Fig. 5.b the execution drawing of the cutting tool is shown, with its design dimensions.

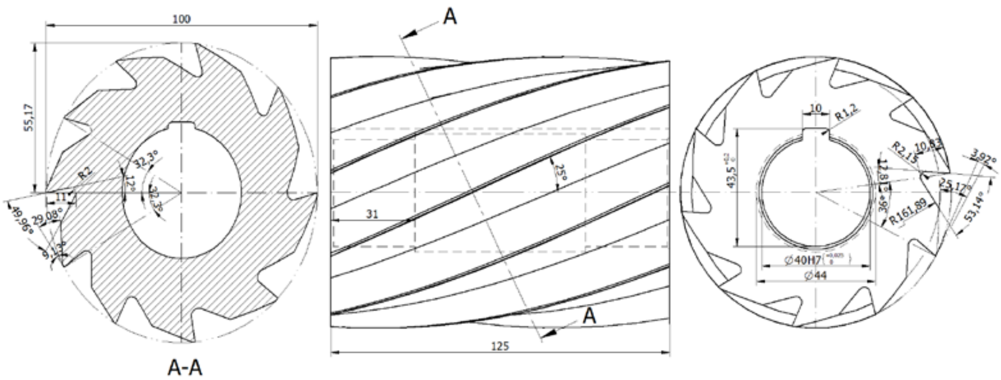
3. MILLING OF HELICAL GROOVES OF CYLINDRICAL CUTTING TOOLS

To solve the theoretical and practical problems of milling the helical grooves of cylindrical cutting tools, the following stages should be performed:

- calculation of positioning elements of cutting tools to the semi-product;
- calculation of the adjusting elements of the milling machine;
- control of geometrical and design parameters of the teeth.



a)



b)

Fig. 5. 3D Model and execution drawing of the cylindrical cutting tool

The most important problem is the calculation of the positioning elements of the cutting tool to the semi-product.

To obtain the given angle of clearing the way of the cylindrical cutting tool teeth, the cutting tool should be moved in horizontal direction to the axis of the semi-product with *u* distance, and with *v* distance vertically, as in Fig. 6.a.

To calculate *u* and *v* movements, the section of the milling groove of the cutting tool is considered in $X – X$ axial plane.(Fig. 6)

This section is an ellipse whose *m* and *n* semi-axes are calculated by the formulae:

$$n = \frac{R}{\cos\eta} \qquad m = R \tag{12}$$

where R is the radius of the semi-product.

The curve radius of R_1 is determined with the formula:

$$R_1 = \frac{R}{\sqrt{1-(\sin\eta)^2\,[\sin(\gamma+\theta)]^2}}. \tag{13}$$

When the helical groove is milled, with ω inclination angle, with bi-conical angular cutting tool, η rotation angle of the body of the milling machine can be determined in Fig. 6.b, the pitch of the helical grove having been given by the formula:

$$P = 2\pi \cdot R \cdot \cot\omega, \tag{14}$$

The coordinates of a point B on the surface of the semi-product, which is found on the helix with ω angle, and is rotated with ε angle to the generator that passes through point A, Fig. 10.1b, can be determined with the formulae:

$$x = \varepsilon \cdot R \cdot \cot\omega \qquad y = R \cdot \sin\varepsilon \tag{15}$$

The inclination angle of the tangent to the helical line in any point B, can be determined with,

$$\tan\eta = \frac{dy}{dx} = \frac{R\cdot\cos\varepsilon}{R\cdot\cot\omega} = \tan\omega\cdot\cos\varepsilon \quad \text{or} \quad \tan\eta = \tan\omega\cdot\cos(\gamma+\theta), \tag{16}$$

where: γ is the angle of clearing the way of the processing cutting tool tooth, in degrees; θ – lateral angle of cutting tool, in degrees.

Two cases of positioning groove profile to vertical axis of the semi-product can come up in practice, and the cutting tool may or not may have radius on the top: the groove profile intersects the vertical axis of the semi-product and the cutting tool has radius on its top, Fig. 7.a; the groove profile does not intersect the vertical axis of the semi-product and the cutting tool has no radius on the top. Fig. 7.b.

Horizontal movement of the cutting tool is determined from ΔOeK with the formula,

$$u_0 = Oe\cdot\sin(\theta+\gamma+\beta), \text{mm} \quad \text{or} \quad u_0 = T\cdot\sin(\theta+\gamma+\beta), \text{mm} \tag{17}$$

Vertical movement of the v_0 cutting tool is calculated with the formulae,

$$v_0 = R - eK\,,\;\; eK = Oe \cdot \cos(\theta + \gamma + \beta),\;\; v_0 = R - T \cdot \cos(\theta + \gamma + \beta), \text{ mm,} \tag{18}$$

where: *TOe* segment, which is determined by the theorem of sinuses from ΔOde triangle with the formula:

$$T = \frac{R_1 - cd}{\cos\beta}\ \text{, mm;} \tag{19}$$

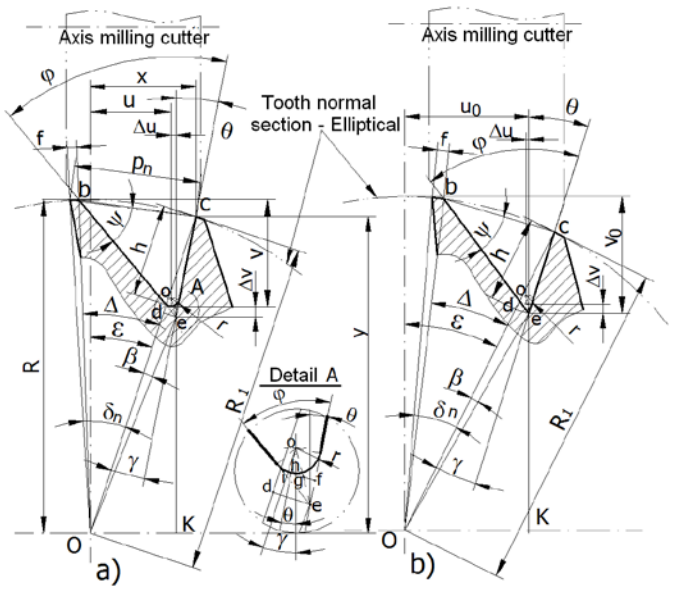


Fig. 7. Groove profile position to the vertical axis of the semi-product

where: $cd = h$ for cutting tool with no radius on the top; $cd = h + \dfrac{r}{\cos(\gamma - \theta)}$ for cutting tool with radius at the top, this formula results from *Detaliu A*, where $\Delta oih \equiv \Delta efg$, according to criterion UUU, and $oh = fe$, and from Δoih it comes that $oh = \dfrac{r}{\cos(\gamma - \theta)}$ and $cd = h + fe$; β – angle occurring due to the clearing angle $\gamma > 0$ ($\beta = 0$, when $\gamma = 0$) and is determined from angle ΔOed with the formulae:

$$\tan\beta = \frac{de}{R_1 - cd} = \frac{cd \cdot \tan\gamma}{R_1 - cd}\,,$$

$$\tan\beta = \frac{\left[h\cos(\gamma - \theta) + r\right]\tan\gamma}{R_1\cos(\gamma - \theta) - \left[h\cos(\gamma - \theta) + r\right]} \tag{20}$$

where: h is the height of the tooth, in mm; r – radius at the tip of the cutting tool, in mm;

In general, helical cutting tool groove is based on r connecting radius, which reduces the movements along the two directions with Δu and Δv, determined with the formulae,

$$\Delta u = oe\sin\left(\frac{\varphi}{2}-\theta\right),\ oe = \frac{r}{\tan\frac{\varphi}{2}}\sqrt{\tan^2\frac{\varphi}{2}+1},\ \Delta u = \frac{r\sin\left(\frac{\varphi}{2}-\theta\right)}{\tan\frac{\varphi}{2}}\sqrt{\tan^2\frac{\varphi}{2}+1} \quad (21)$$

$$\Delta v = \frac{r\cos\left(\frac{\varphi}{2}-\theta\right)}{\tan\frac{\varphi}{2}}\sqrt{\tan^2\frac{\varphi}{2}+1}-r \quad (22)$$

The movements of the connected tip of the cutting tool to the superior generator of the semi-product according to the two axes, are determined according to the formulae:

$$u = u_0 - \Delta u \quad (23)$$

$$v = v_0 - \Delta v \quad (24)$$

4. CONCLUSIONS

The shape, precision and quality of machined pieces depend on the characteristics of the machine-tools and cutting tool, by design, execution and relative positioning precision to the piece.

By the use of 3D modelling of softwares of chipping tools, these design problems are solved with a good productivity and possibilities of execution, behaviour simulation in the process of chipping and checking the resistance of the active part of the tool. In the case of 3D modelling cylindrical cutters with helical teeth, the equations given in literature are checked [2, 3], by simulating generation conditions of surfaces for the active part of helical teeth of cylindrical cutters and carrying out various sections to highlight the values of design and working angles. In most of the literature of specialty regarding the chipping tolls design, generation of helical grooves is based on a point on the axial generator of the semi-product, as in the case of teething of toothed wheels with inclined teeth, and not laterally moved as in the case of positioning cutting tools to machine helical grooves of cutters.

As a result of 3D modelling of cylindrical cutting tools with helical teeth, the specifications in the literature of specialty are confirmed, [2], in the sense that in frontal plane, the profile of the clearing face and back of the tooth is not made up of right lines but of curves, arcs, which leads to variable clearing angles, figure 8. The difference between the angular pitch and the sketch of the groove profile figure 3 and the normal section on the groove figure 5 are noticed.

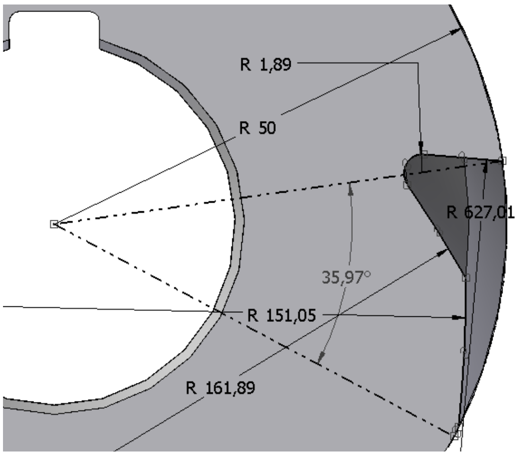


Fig. 8. Groove profile in the frontal plane of the cutter

In the future, I endeavor to make an analysis of the tooth profile following helical groove machining by milling, with bionic cutting tool.

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