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Algorithms for design of single flute end mill cutters

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Abstract— In this article, designed as a set of three interconnected elements are presented algorithms for analytical and graphical profiling of single flute end mill cutters for manufacturing of aluminium profiles, composite and HPL panels, as and methodology for graphic profiling in an environment of CAD system TopSolid.

Index Terms— cutting tools, single flute end mill cutters, high-speed milling (HSM), analytical and graphical profiling, CAD systems

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1 INTRODUCTION

Single flute end mill cutters function under extremely intense cutting conditions. At their contact surfaces are realized serious normal and tangential stresses, as well as relatively high temperatures, which can reach up to about 500÷550°C. In such conditions occurs an intense friction, adhesion and diffusion process.

2 PART I – ANALYTICAL PROFILING

2.1 Introduction in part I

Formation of the flute of single flute end mill cutters, implemented by milling disc and milling machines and grinding with profiled discs. The determination of the axial profile of the cutting disk tools (profiling) is a task requiring analytical or graphical solutions. Based on hypothesized whereby the contact surface between the rotary cutter and screw formed flute is non-linear and spatial and can be represented as a set of tangent points in normal's always pass, through the axis of the cutting tool in case in the case of disc milling cutter [3], [6],[8].

2.2 Algorithm for analytical profiling

Analytical profiling detailed in sources [3],[6],[7] requires at specify explicitly vector equations of the helical line and the orientation of the tool, at a fixed position of the workpiece, such that its axis is perpendicular to the workpiece –fig.1, communication between them to express complex spatial continuous line lps.

$$r = f_1(\rho,\theta).i + f_2(\rho,\theta).j + f_3(\rho,\theta).k \quad (1)$$

where:

- $f_1(\rho,\theta)$, $f_2(\rho,\theta)$, $f_3(\rho,\theta)$ – equations of x,y,z,
- i,j,k – singles vectors.

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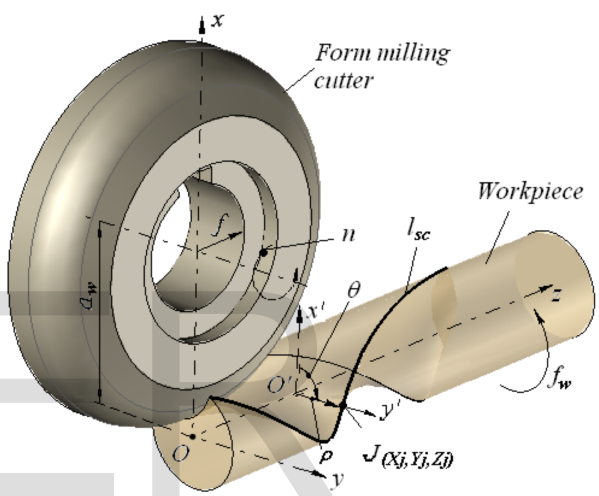

Fig. 1. Formation of the profile of the workpiece with a disc milling cutter in a helix line

The rotation of this line lps about the tool axis Oy, formed his profile - fig.2.

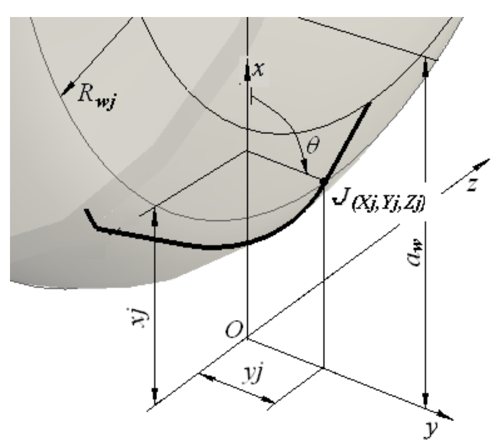

Fig. 2. Theoretical profile

In this instance, the coordinates of the points of the cutting

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edges of the disc cutter to satisfy the equations of screw line forming flute on the workpeace (single flute end mill cutters), i.e. they may belong to both a front of the tool surface and the detailed helical surfaces.

General rule of points belonging to the helical line lps expressed by dependence (2) [3], [6]:

$$(X-x)/n_x=(Y-y)/n_y=(Z-z)/n_z \tag{2}$$

where:

- X,Y,Z – coordinates of current points normal,
- x,y,z – coordinates of contact points,
- n_x,n_y,n_z – projections of the normal vector on the axes x,y,z.

Algorithm profiling should fully specified source [6] methodology.

If any point J of normal spell out conditions determining the geometric limitations of the type - coordinates (X, Y, 0), the dependence (2) takes the form [6].

$$(X-x)/n_x=(Y-y)/n_y=-z/n_z=F_0(\rho,\theta) \tag{3}$$

If one examined in point a spatial location defined by the coordinates x, y, z, build a plane perpendicular to the tool axis OXZ, is formed rotationally-sectional view of the disk shaped tool having a radius Rwj.

$$R_{wj}=a_w-\sqrt{(x^2+y^2)}=$$

$$a_w-\sqrt{\left(X^2+Y^2\right)+\frac{2z}{n_z}\left(X.n_x+Y.n_y+\frac{z}{n_z}(n_x+n_y)^2\right)}$$

Set of equations:

$$\begin{aligned}&x=f(\rho,\theta),\\&y=f(\rho,\theta),\\&R_{w0}=a_w-\\&\sqrt{\left(X^2+Y^2\right)+\frac{2z}{n_z}\left(X.n_x+Y.n_y+\frac{z}{n_z}(n_x+n_y)^2\right)}\end{aligned} \tag{5}$$

determined axial instrumental profile.

In turn, let us assume that at the same point J equation of a helix lsc is defined by the coordinates of its surface, located in axial plane OXY detailed coordinates O, x, y, z. [3], [8].

$$\begin{aligned}&X=\rho_j.cos\theta\\&Y=\rho_j.sin\theta\\&Z=Z_j+p\theta\end{aligned} \tag{6}$$

where:

ρj – radius vector of the axis Oz to the j-th point,mm;
θ – angle parameter of the helical line, rad;
ρ=P/2π – angle parameter of the screw line,mm/rad;
P – pitch of helical line,mm.

A basic equation of the projections of the normal vector expressing system draws [8]:

$$\begin{aligned}&n_x=(\partial y/\partial\rho).(\partial z/\partial\theta)-(\partial y/\partial\theta).(\partial z/\partial\rho)\\&n_y=(\partial z/\partial\rho).(\partial x/\partial\theta)-(\partial z/\partial\theta).(\partial x/\partial\rho)\\&n_z=(\partial x/\partial\rho).(\partial y/\partial\theta)-(\partial x/\partial\theta).(\partial y/\partial\rho)\end{aligned} \tag{7}$$

That after taking into account conditions (6) mined type [6]:

$$\begin{aligned}&n_x=p.sin(\theta)+\rho.Z_j.cos\theta\\&n_y=-p.cos(\theta)+\rho.Z_j.sin\theta\\&n_z=\rho\end{aligned} \tag{8}$$

Analytical profiling of single flute end mill cutters – universal, normal with right hand spiral for right hand cutting and polyhedral profile-ground style, manufactured form high-speed steel HSS Co8, requires joint solving equations (8) and (3), on parameters ρ and θ, thereby resulting equation:

$$F_0(\rho,\theta)=\frac{Zj+P.\theta}{\rho} \tag{9}$$

The decision dependence upon different values of ρ and θ give polar coordinates for each point xj,yj,Rwj, pleasing condition F0≤0,0001 [6] which iteratively generates the desired axial tools profile. In specify zero values of xj = 0, the profile is formed in a plane perpendicular to the axis of the tools – fig.3.

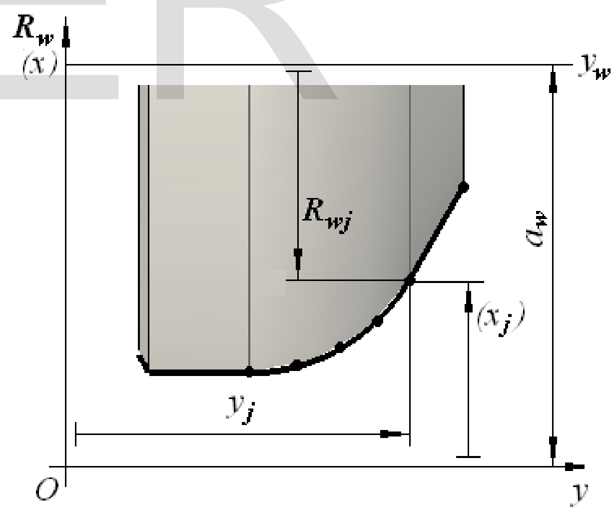

Fig. 3. Generating axial tool for disc milling cutter

2.3 Conclusion of part I

2.3.1 Analytical profiling is performed at a constant position of the workpiece, whose axis is perpendicular to that of the tool.

2.3.2 A complex continuous spatial curve forming the instrumental profile, reflects the contact between tool and workpiece and generate the coordinates specified with random values of the parameters-

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ρj – radius vector and θ-angle parameter of the helical line.

3 Part II – Graphical profiling

3.1 Introduction in part II

Graphical profiling of tool – disc milling cutter for the manufacturing of flute for detail single flute end mill cutters is realized by a combination of consistently made graphic constructions based on the profile of flute from which successively phased generated profile of the tool. The methodology is fully consistent with presented in [4].

3.2 Algorithm for graphical - analytical profiling

At any moment accompany the process of cutting, tool and workpiece occupy certain spatial position. The projection of the tool at that point on the arbitrary plane perpendicular to its axis is a circle, and that of flute a complex curve contacting to a common point. Family of such secant planes allows obtaining various tools and detailed profiles.

The graphical - analytical profiling shown in fig.4 passes through several typical step [4]:

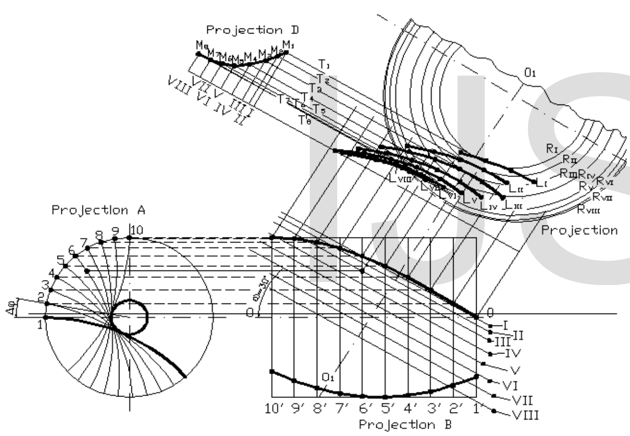

Fig.4. Graphical - analytical profiling [4]

3.2.1 Setting profile of flute projection A and its propagation around the tool axis in a polar array divergence Δφ=π/10 in ten positions.

3.2.2 Design of the profile on an axial plane - projection B. The axial distance for the construction of grid 1', 2', ..., 10' is obtained by:

$$\Delta P = D.\Delta\varphi / 2tg\omega \quad (10)$$

where:

ω – helix angle.

The projection of the points 1,2, ... 10 formed in the helix- in line of the flute.

3.2.3 Sweep of milling cutter axis O-O_1, below angle δ = 90°-(ω+2°).

3.2.4 Plotting the planes I, II, ... VIII, perpendicular to the axis of the tool.

3.2.5 Generating projection C as the intersection of the helical surface with the planes I, II, ... VIII. The resultant curves are marked as LI, LII, ... L VIII. Tangents to the curves LI, LII, ... L VIII, coaxial circles, forming the instrument profile. In determining the radii of these circles RI, RII, ..., RVIII, as the base is used largest constructive radius reaching the extreme curve [6].

3.2.6 Construction of projection D - spending lines T1, T2, ... T8 parallel to b-b and tangent to the circles with radii RI, RII, ..., RVIII. Intersection of normals forming secant planes I, II, ... VIII with lines T1, T2 ... T8, the instrument generates profile points by M1, M2, ... M8.

3.3 Horizontal and vertical tool displacement

The analytical and graphical profiling, form the geometry of the tool. Next step in the shaping of single flute end mill cutters is the determination of horizontal and vertical displacement of the tool and the angle of rotation of the mass of milling machine - Fig.5.

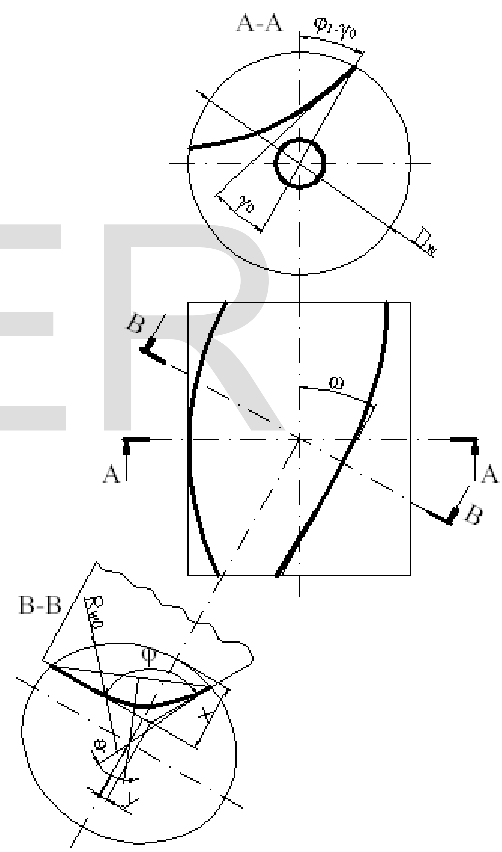

Fig.5. Coordinate displacement of tool [2]

For this to be known - the width of the strip f,mm in poly-hedral profile-ground style tools, the diameter - Dw, mm, rake angle, central tool angle φ and detailed central corner angle - ε_r [2], [4].

Dependencies are displayed in [2],[8].

$$\varepsilon = \left(2\pi - \frac{2f}{D_w}\right) \quad (11)$$

$$x = \frac{d}{2}\left\{1 - \cos\gamma + \frac{2\sin\frac{\varepsilon}{2}\cos\left[(\varphi - \gamma_0) - \frac{\varepsilon}{2}\right]}{\sin\varphi}\right\} \qquad (12)$$

$$y = \frac{d}{2}\left\{\sin(\varphi + \varphi_1) - 2\sin\frac{\varepsilon}{2}\cos\left[\frac{\varepsilon}{2} - (\varphi - \gamma_0)\right].\frac{\sin\varphi_1}{\cos\varphi}\right\} \qquad (13)$$

Regarding the rotation angle of the table will examine where projection B-B [2]

To avoid clipping teeth at large values of ω, angel of turning the mass of milling machines ω_1 is calculated as:

$$tg\omega_1 = tg\left(\frac{\pi.D_w}{P}\right).\cos(\varphi_1 - \gamma_0) \qquad (14)$$

where:

R – radius of the workpiece.

The determination of the radius of curvature of the section characterized in a minor orthogonal plane P_o' has an elliptical shape and are calculated according [2]:

$$R_{w0} = \frac{R_w}{\cos^2\omega} \qquad (15)$$

3.4 Conclusion of part II

3.4.1 The construction of the graphic profile of the tool is implemented by successive graphic constructions forming a family of secant planes.

3.4.2 Precise milling of flute of single flute end mill cutters, after profiling tool in case milling cutter, to determine process parameters oriented system - horizontal and vertical displacement of the tool and the angle of rotation of the mass of the milling machine.

Part III – Graphical profiling with TopSolid'Design

4.1 Introduction in part III

Graphic profiling than in the traditional algorithm with geometric constructions and interceptions could be realized through the use of CAD/CAM/CAE hybrid parametric and associative CAD systems. In the case selected system TopSolid'Design, this has extensive tool apparatus suitable for shaping of equipment of this type [1], [5]. Often in practice the design of technological processes for the manufacture of fundamentally new design tools or those with complex shape of the cutting part, the tool is profiled analytical and graphical modelling is only used to control the accuracy of the calculations.

4.2 Profiling cycle with CAD system

The algorithm for generating the tool geometry using a 3D model of the universal single flute end mill cutter with right hand spiral for right hand cutting and polyhedral profile-ground style, manufactured form high-speed steel HSS Co8, following sequence involving six main stages [1], [5].

4.2.1 Creating a geometric model of the workpiece

Modeling of solids in TopSolid offers opportunities for the construction of rotary parts related to technology for their manufacture. They are pretty clear in [1]. In this case, use functionality to create base rotational-symmetrical body - **Create contour/Turning**, type document - **Design** with extension (*** .top**) - fig.6.

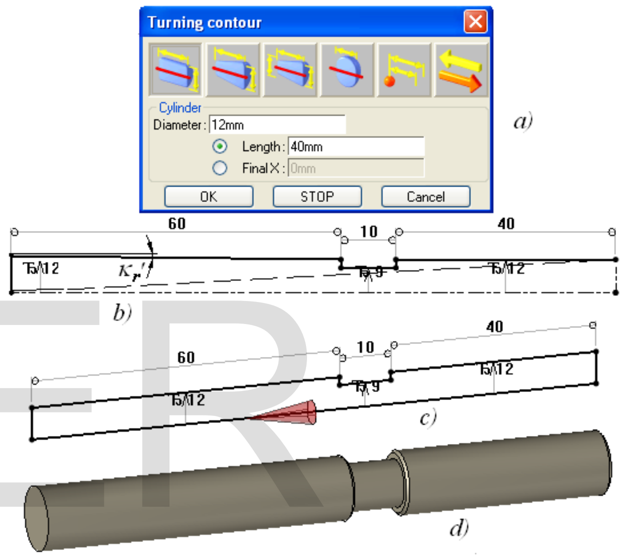

Fig. 6. Creating a geometric model of the workpiece [1]

The format of the command requires the definition of the type of turning contour, diameter and length of each element of the piece. Data is recorded consistently active windows of dialog frame - figure 6,a.

After entering the data for the last loop system requires its confirmation tick **Stop**.

The construction of rotary - symmetrical body requires forming a third dimension through full rotational prepared a sketch of about x axis by an operation **Create revolved shape**.

4.2.2 Generating of the workpiece according to the part model

Implemented by function "**Enclosing Shape",** constitutes forming a cylindrical three-dimensional primitive type according to limit spatial coordinates of the body.

Through the operation to create models of blanks, and about the detail generate additional volume of material, encasing it in all directions. The function is implemented in a mode of cylindrical envelopment - fig.7,a. It is run by Toolbox built as a sequence of dialog boxes.

Once selected mode enveloping system, required by the dialog framework to be referred to the additives and mechanical processing - fig.7,b, and the pulling direction.

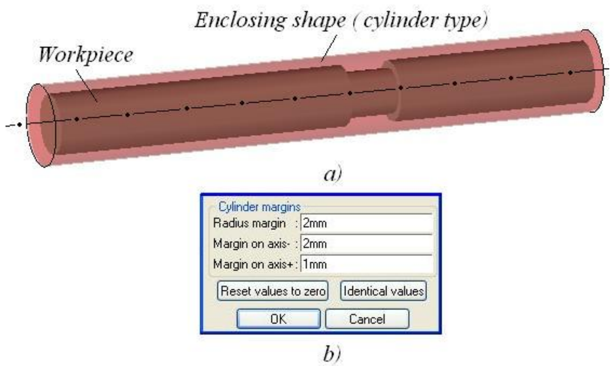

Fig. 7. Generating of the workpiece [1]

4.2.3 Create tool - disc shaped milling cutter

The desired tool profile is built with built with the help of geometric primitives form menu **Sketch - line/circle,** arc in working for TopSolid plane oriented set of modulators activated via keyboard shortcuts **Current coordinate system / Coordinate system / Coordinate system on plane**.

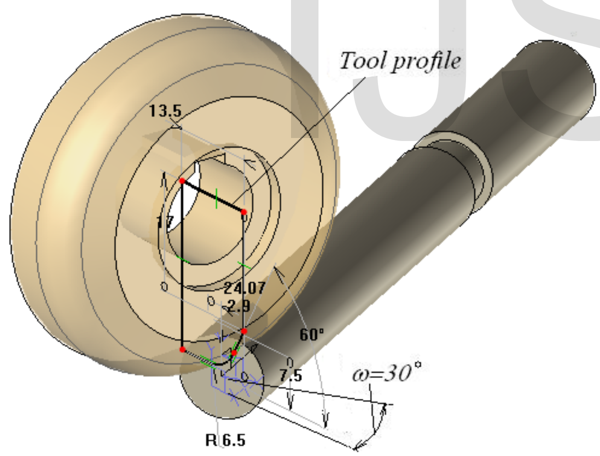

Fig. 8. Create tool - disc shaped milling cutter [1]

In terms of geometry single flute end mill cutters this is a normal plane or which rotates milling machine tool supporting disc shaped cutter in shaping flute of the detail. It is offset angle ω – fig.8. In terms of TopSolid this is realized through the dialog framework activated by a button **modify element**, which sets out options for a selected coordinate rotation axis around random coordinate axis. The body of the tool is modeled again by surgery **Create revolved shape**.

4.2.4 Forming of flute

Explicit equation of screw line (6) in this case is realized through technological function modeling spiral surface **Spiral/Helix**. The command launches a dialog framework parametric definition of a helix fig.9. Available features are set in the digital form and graphically interpreted in different areas of the frame.

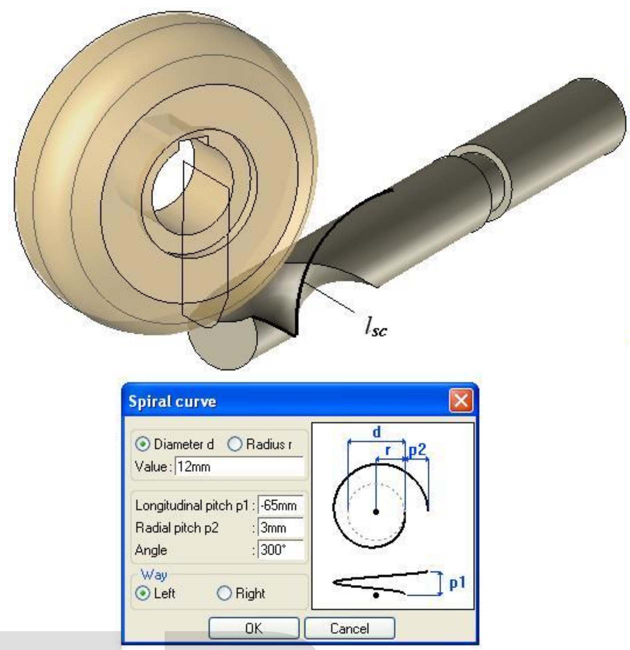

Fig. 9. Forming of flute [1]

Thus, the resulting curve presents the trajectory along which slides the tool profile for realizing flute. It is possible that this operation be performed through commands belonging both solid state and the surface modeler in TopSolid.

- this is about solid state function **Pipe, on curves** consist of the guiding line "**Guide curve"** in the case and screw line section **Section curves**.

- on the surface is using a function **Swept**. It creates a model by swept the section on leading spatial curve. In the case of using the format - sliding along a curve leading to a cross-section. Method of keeping a **freenet** - profile loosely follows the guide curve without additional geometric constraints imposed.

Physical withdrawal of the metal is simulated by using a boolean operation **Subtract** - manifested in the withdrawal of capacity from basic (existing) model in the case detail, corresponding to the volume of previously incorporated in him another body - tool.

4.2.5 Ensuring the geometric parameters of single flute end mill cutter

Provide the formation of the axial relief angles in the axial plane - α_{p1}=5° and α_{p2}=30° - fig.10. For this purpose built axial plane in the prescribed manner. It shapes the contour of the grinding tool performs sharpening. Builds body is an tool "**Create revolved shape"** and based on it, removes material layer by binary operation **Subtract** from the workpiece.

In single flute end mill cutters interest are more two angles

– first α_{p1} =0÷18° and second axial relief angle α_{p2} =18÷45°. These are the angels of providing incision of tools. They are depend of the type of manufacturing material and tooling major flank surface.

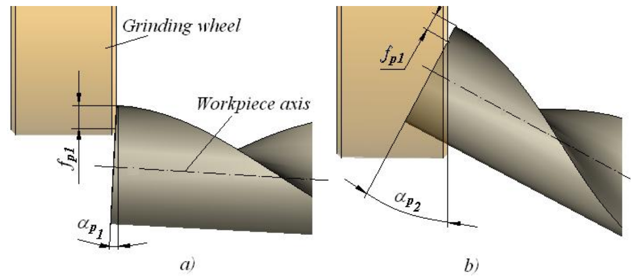

Fig.10. Providing of tool geometry [1]

4.2.6 Forming the back surface

Depending on the shape of the surface, apply a variety of options. For specific details with polyhedral profile-ground style tool to simulate the process of grinding the area with length by means of a flat disk fα, the resulting surface propagated by tool creating an array of copies helical line - **Propagate/Helical**. CAD tools for realization of the command are:

- forming technological groove with operation **"Groove"**, out of the grinding disc forming the back surface – fig.11.
- selection of a reference axis,
- interval,
- number of elements,
- an indication of the base point.

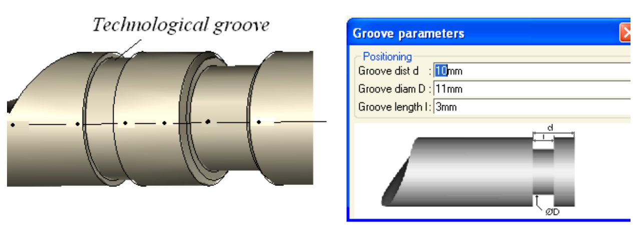

Fig. 11. Cutting of groove [1]

In the presence of relief surface, apply analytical methods for profiling, where curves of relieving, which are equidistant are replaced by concentric circles with center coinciding with that of the replaced archimedean spirals. This greatly simplifies the shape of the relieving grinding disc and reduces guidance of tool – fig.12.

4.3 Conclusion of part III

4.3.1 The algorithm for generating tooling geometry in 3D environment should technological sequence in the manufacturing of tools

4.3.2 The model is implemented identical operations – manufacturing the tool profile, milling of flute and grinding surfaces providing geometric parameters.

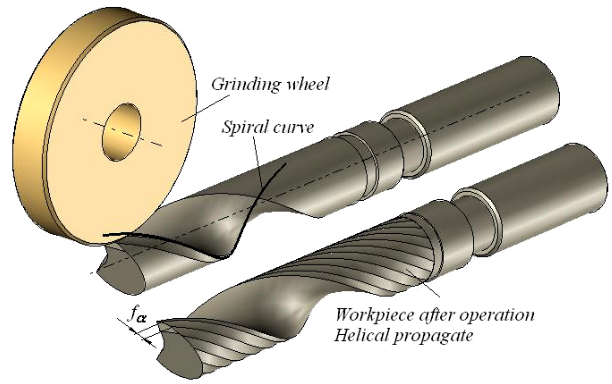

Fig. 12. Forming of polyhedral profile-ground style [1]

5 General conclusion

1. Performed is analytical profiling
2. Exposed is algorithm for graphical - analytical profiling with displacement of tool.
3. Proposed methodology for graphical profiling in environment of CAD systems TopSolid'Design.

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