COMPARATIVE STUDY OF DRILL'S FLANK GEOMETRY DEVELOPED WITH THE CATIA SOFTWARE

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ABSTRACT

The paper presents a comparative study for the geometry of standard twist drill's flank as oppossed to curved multi-edge drills for a similar sharpening process, on a cylindrical surface. Developed through the resources provided by graphic design CATIA software, the study refers to the shape of the face, the variation law of the tool normal clearance, along the cutting edge and to the clearance of the face.

KEYWORDS: twist drills, sharpening layout, tool normal clearance, clearance of face

1. INTRODUCTION

The study of the twist drill active surface and its geometry is the subject of research for many scholars, who use mostly analytical methods. The results were published by Hsieh [1], [2], Zhang [3], Paul [4], for tools with straight cutting edges. Also, for the same type of tools (twist drills) but with a curved cutting edge, with a variable angle of attack, a significant analysis was presented by Fetecău [5], [10].

In both cases, straight edge drills, curved edge drills, the cutting edge is considered to result from the intersection between the twist channel of the drill (cylindrical twist of constant lead) with placing surface, as resulted from the pre-determined cutting layout – twisted, cylindrical or conic surface for straight edge drills or toroid, conic, cylindrical for curved edge drills [5], [10], [11], [12]. The study through analytical methods of the placing surface geometry for twist drills, although a universal and compelling method, can have some limitations when trying to represent the shapes of these surfaces, especially if it is aimed to, eventually, create new cutting layouts [11], [12]. The present paper is looking to a developed method in the CATIA design software which, by resorting to principles of generating winding surfaces [6], [13], [14], [15], the case of generating placing surfaces as a result of winding alternate positions of abrasive objects (revolution objects), can create 3D models of these surfaces and allows the study of these surface's shapes, using programming methods in VBA, included in CATIA.

An elementary study of the placing surface of a standard twist or curved drill's blade implies: determining the variation law for the size of the placing angle along the main edge of the blade, the clearance study of the entire placing surface, the study of the drill's transversal blade shape.

The paper presents the analysis of cutting process through methods offered by the CATIA platform – sharpening after or both types of drills: standard, with straight cutting edge, multi-edged, with curved cutting edge (variable angle of attack) [16].

2. LAYOUT FOR CYLINDRICAL CUTTING – THE ANALYTICAL METHOD

For the twist drill (straight cutting edges), the process of creating the placing surface through cutting with an object – rotation cylinder, is presented in figure 1.

At the same time, reference systems which the sharpened drill and the generating abrasive object refer to, are presented: $X_0Y_0Z_0$ – is a mobile system, associated with the abrasive object(cylindrical surface of revolution); XYZ – mobile system, with the Z axis overlapping the axis of the generated cutting surface; xyz – a fixed system, associated with the sharpened drill.

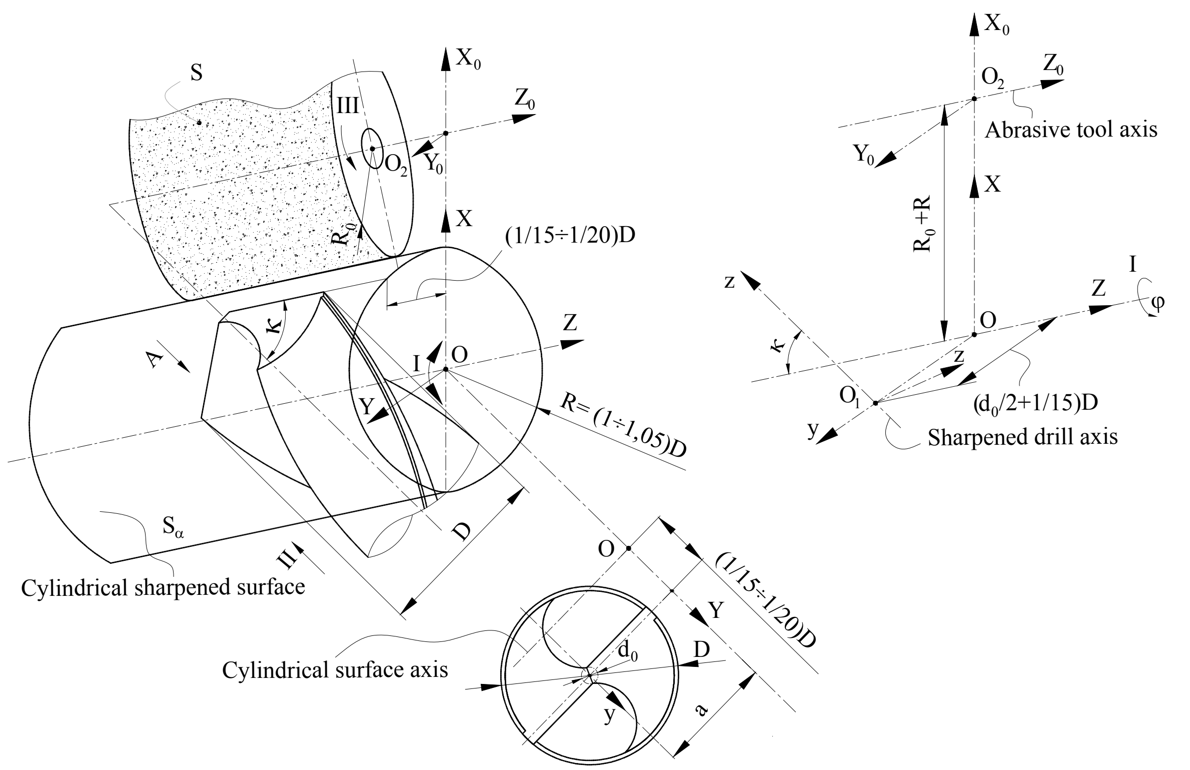

Fig. 1. *Cylindrical sharpening of the straight edge drill: kinematics and reference systems*

The kinematics of the shaping process for the placing surface entails performing a set of movements:

I – the swinging motion of the drill around the Z axis – the axis of the cylindrical cutting surface on the placing surface;

II – the feed motion, discontinuous, along the drill's axis;

III – the cutting movement, the rotation of the abrasive object;

Surface *S* – in the system $X_0Y_0Z_0$ – is defined by the following:

$$S\left|\begin{aligned} &X_0 = R_0 \cdot \cos\theta;\\ &Y_0 = R_0 \cdot \sin\theta;\\ &Z_0 = t,\end{aligned}\right. \tag{1}$$

with θ and t – independent variable parameters.

Surface *S*, in the kinematics ensured by the sharpening process, describes a family of surfaces whose curve is the sharpening surface - Σ .

The rotation movement of the system $X_0Y_0Z_0$, around the axis *Z* is described by the following transformation:

$$X = \omega_3^T(\varphi)\left[X - \begin{Vmatrix} -(R_0+R) \\ 0 \\ 0 \end{Vmatrix}\right] \tag{2}$$

generating the set of surfaces $(S)_\varphi$:

$$(S)_\varphi \begin{Vmatrix} X \\ Y \\ Z \end{Vmatrix} = \begin{Vmatrix} \cos\varphi & -\sin\varphi & 0 \\ \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{Vmatrix} \cdot \left[\begin{Vmatrix} R_0 \cdot \cos\theta \\ R_0 \cdot \sin\theta \\ t \end{Vmatrix} - \begin{Vmatrix} -(R_0+R) \\ 0 \\ 0 \end{Vmatrix}\right] \tag{3}$$

In principle,

$$(S)_\varphi \begin{aligned} X &= X(\theta, t, \varphi);\\ Y &= Y(\theta, t, \varphi);\\ Z &= Z(\theta, t, \varphi).\end{aligned} \tag{4}$$

whose curve is the sharpening surface Σ .

Associating to the equations (4) the winding restriction, in the Gohman form [13]:

$$\vec{N}_{S_\alpha} \cdot \vec{R}_\varphi = 0 \tag{5}$$

with $\vec{N}_{S_\alpha}$ - normal to the surface *S*, from (1)

$$\overrightarrow{N_S} = \begin{Vmatrix} \vec{i} & \vec{j} & \vec{k} \\ -R_0 \cdot \sin\theta & R_0 \cdot \cos\theta & 0 \\ 0 & 0 & 1 \end{Vmatrix} \tag{6}$$

and $\vec{R}_\varphi$ - speed vector, from (2).

$$R_{\varphi} = \frac{dx}{d\varphi} = \omega_3^T(\varphi) \cdot \left[\begin{Vmatrix} R_0 \cdot \cos\theta \\ R_0 \cdot \sin\theta \\ t \end{Vmatrix} + \begin{Vmatrix} (R_0 + R) \\ 0 \\ 0 \end{Vmatrix} \right], \quad (7)$$

In principle,

$$\vec{R}_{\varphi} = R_{\varphi_x} \cdot \vec{i} + R_{\varphi_y} \cdot \vec{j} + R_{\varphi_z} \cdot \vec{k}. \quad (8)$$

The curving restriction is basically given by the relation:

$$g(\theta, t, \varphi) = 0 \quad (9)$$

which, associated to the set of equations $(S)_{\varphi}$ (4), defines the sharpening surface Σ, in the X*YZ* system, as follows:

$$\Sigma \left| \begin{aligned} &X = X(\varphi, t); \\ &Y = Y(\varphi, t); \\ &Z = Z(\varphi, t). \end{aligned} \right. \quad (10)$$

This surface relates to the reference system of the twist drill, *xyz*, through the transformation:

$$x = \alpha[X - A] \quad (11)$$

in which: α is the matrix of the orthogonal transformation,

$$\alpha = \begin{Vmatrix} \cos x & 0 & \sin x \\ 0 & 1 & 0 \\ \sin x & 0 & -\cos x \end{Vmatrix};$$

$$A = \begin{Vmatrix} 0 \\ \frac{d_0}{2} + \left(\frac{1}{15} \ldots \frac{1}{20}\right) \cdot D \\ -a \end{Vmatrix}. \quad (12)$$

a – process constant (geometrically arbitrary). The equations of the placing surface are thus defined in the reference system associated to the sharpened drill:

$$\Sigma \left| \begin{aligned} &x = x(\varphi, t); \\ &y = y(\varphi, t); \\ &z = z(\varphi, t). \end{aligned} \right. \quad (13)$$

It is now possible to study the sharpening quality, using this analytical method regarding: the variation law for the size of the placing angle, along the main blade, the relieving of the entire placing area.

Both problems can be rigorously solved, if we consider intersections of the Σ surface (13) with coaxial cylinders with the sharpened drill, by the equations:

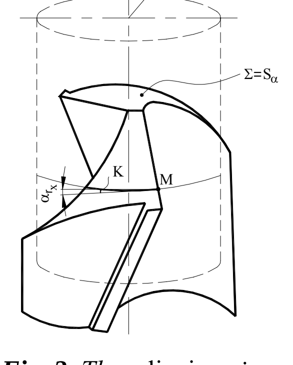

Fig. 2. *The* relieving *size and the placing angle (on r_x radius cylinder)*

$$\left| \begin{aligned} &x^2 + y^2 = r_x^2; \\ &z = t. \end{aligned} \right. \quad (14)$$

with r_x and *t* arbitrary variables.

We can analytically define the size of the placing angle for the drill and the relieving corresponding to a r_x size of the cylinder's radius that we are considering $\left(\frac{d_0}{2} \le r_x \le \frac{D}{2}\right)$ - figure 2. The size of the *K* relieving is defined by the distance between the intersection of the area S_{α} with the r_x radius cylinder and the normal plane to the drill's axis, passing through the point M on the blade. The placing angle α_{r_x} is defined between the tangent to the intersection curve of surface S_{α} with the r_x radius cylinder and the normal plane on the drill's axis.

3. SHARPENING OF CURVED MULTI-EDGE DRILLS – ANALYTICAL METHOD

In figure 3, the kinematics for the formation of the main blade's placing surface is presented, in the case of a drill with three circular curved blades.

The reference systems XYZ are defined – mobile system, similar to the sharpening area – S_{α}; *xyz* – fixed system, similar to the sharpened drill's axis.

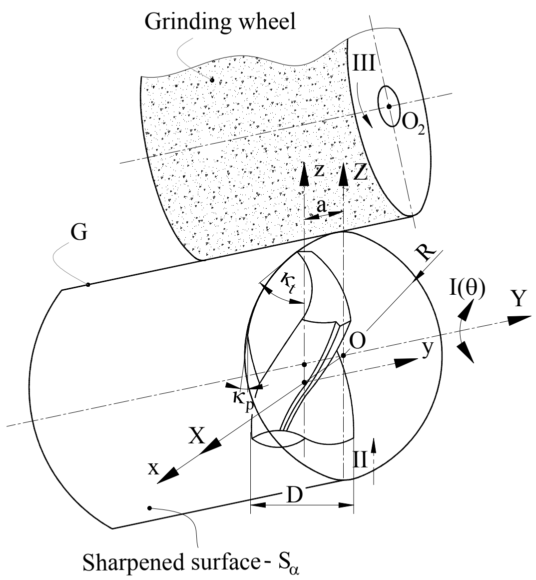

Fig. 3. *Cylindrical sharpening of the curved edge drill: kinematics and reference systems*

The kinematics of the sharpening process involves the following movements:

I – the swing motion of the drill around the axis of the sharpening surface;

II – discontinuous feed motion;

III – cutting movement, performed by the abrasive object.

It is considered that the generating line of the abrasive object produces, in relation to the XYZ system, a cylindrical surface of revolution.

In the *XYZ system*, the equations of the cutting edge are:

$$\begin{vmatrix} X = R\cdot\cos\theta; \\ Y = 0; \qquad \text{with } \kappa_p \le \theta \le \kappa_t \\ Z = R\cdot\sin\theta, \end{vmatrix} \qquad (15)$$

thus, the cutting surface (the surface generated on the drill as a result of the sharpening kinematics) has the following equations:

$$S_\alpha \begin{vmatrix} X = R\cdot cos\,\theta; \\ Y = -t; \\ Z = R\cdot sin\,\theta, \end{vmatrix} \qquad (16)$$

with θ and t – variable parameters.

By changing the coordinates

$$x = \alpha\left[X - A\right]; \quad \alpha = I^* \qquad (17)$$
$$\text{and } A = \left\| a \quad 0 \quad 0 \right\|$$

The equations of surface S_α are in relation to the reference system of the drill.

After substitutions and developments, the equations of the cylindrical surface S_α are derived, in the reference system of the sharpened drill.

$$S_\alpha \begin{vmatrix} x = R\cdot cos\,\theta - a; \\ y = t; \\ z = R\cdot sin\,\theta, \end{vmatrix}$$

$$R = \frac{\sqrt{\frac{D^2}{4} - \frac{d_0^2}{4}}}{cos\,\kappa_p - cos\,\kappa_t}; \qquad (18)$$

$$a = R\cdot cos\,\kappa_t$$

$\kappa_t = 60^0$; $\kappa_p = 5^0 \div 12^0$ - limits of the angle of attack's values; D – drill's diameter; d_0 - drill's core diameter ($d_0 = 0,2\cdot D$).

Relieving lines are defined, in relation to the (18) equations, as being the intersection curves between the drill's coaxial cylindrical surfaces with the drill, of r_x radius variables, figure 4.

$$\left| C_{r_x} \begin{vmatrix} x^2 + y^2 = r_x^2; \\ z = H, \end{vmatrix} \right. \qquad (19)$$
$$\frac{d_0}{2} \le r_x \le \frac{D}{2}$$

H – independent variable.

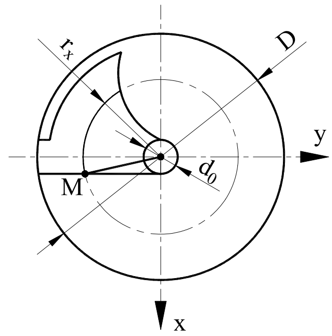

Fig. 4. Relieving *curves*

The set of equations (18) and (19) allows us to determine the analytical model of relieving curves, and from this on, taking into account the previous definitions, we can determine the placing surface's relieving and the size of the placing angle along the cutting edge.

The analytical method of solving the suggested problem and briefly presented before, is laborious. The following is a solution developed in CATIA, characterized by accuracy, speed and exactness.

4. THE 3D METHOD TO STUDY HELICAL DRILL'S GEOMETRY

Developing methods are suggested in the CATIA design software that have as an live 3D modeling of helical drills, of generating specific cutting layouts, as well as the study of the variation law of the back angle along the cutting edge and the relieving of the main back surface.

4.1 Cylindrical sharpening of twist drills

The method entails 3D modeling of the helical drill as well as of the generating abrasive tool relatively positioned, according to the pre-determined generating layout. For cylindrical sharpening of twist drills, the main cutting edge is offset from the oscillation axis in the sharpening process with a *a = (1/15) D* [*mm*] value. Moreover, is presented the distance between the generating line of the abrasive tool and the oscillation axis *Ra = 1D*, in which *D* is the diameter of the sharpened drill's model.

The kinematics of the process requires the cylindrical abrasive tool of R radius to perform a rotation movement around the oscillation axis. It is thus generated a cylindrical surface of revolution, S_α, that constitutes the enwrapping of successive positions for the abrasive tool (*Revolve*), figure 5.

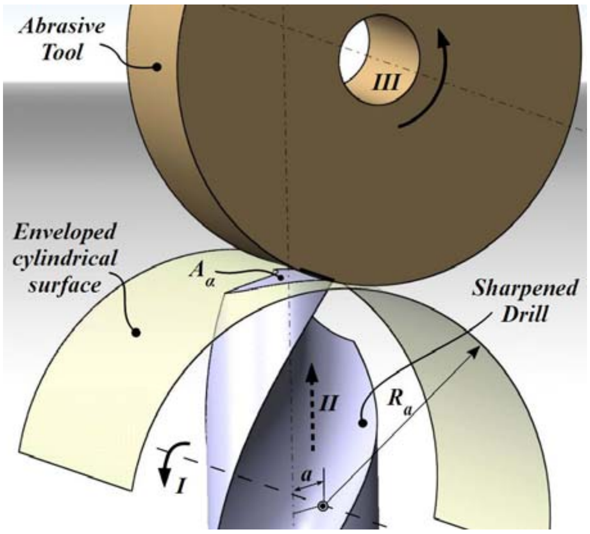

Fig. 5. *3D Models for the twist drill and for the main back surfaces*

Determining the size of the relieving surface takes place by impressing the main cutting edge with a rotation movement around the drill's axis (*Revolve*), generating *Reference Revolute Surface*, figure 5. The value of the relieving on the coaxial cylinders with the drill's axis is defined as the distance measured along the drill's axis between the intersection curves of the back surface *Sα* and *Reference Revolute Surface*, (*Intersection*), figure 6. It is highlighted the fact that the relieving k value rises as the reference cylinders' radii, *Rxi, decrease* (D/2>*Rx* > $d_0/2$).

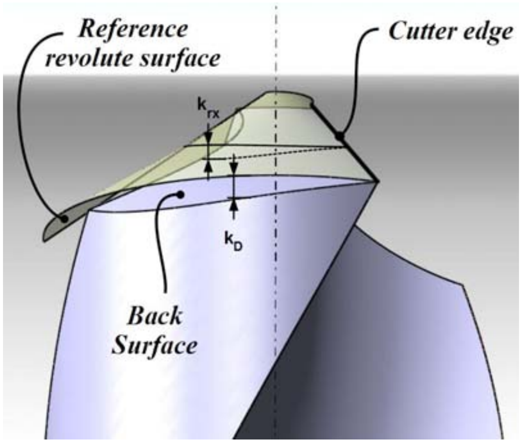

Fig. 6. *Relieving values for the twist drill*

The size of the back angle is defined by the angle between the tangents, figure 7. The back angle increases towards the drill's axis, its minimum value being, in this case, of 11.281^o.

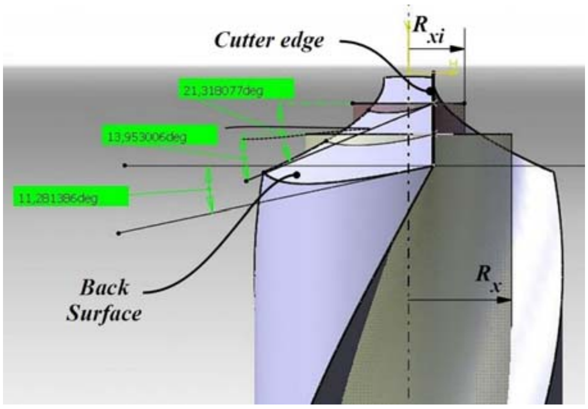

Fig. 7. *Back angles along the main cutter edge*

4.2 Cylindrical sharpening of curved multi-flute drills

It is presented the solid model of the drill with 3 elliptical arc cutting edges, the 3D model of the sharpening surface and the solid model of the abrasive tool in the relative sharpening position, figure 8.

In the generating process (*Revolve),* the main back surface is modeled, - S_α , as being a revolute cylindrical surface of *Ra* radius and offset from the drill's axis with the *a* quota, (18).

The relieving value as well as the back angles' values along the cutting edge are determined in accordance with the previously mentioned method for the sharpening process of twist drills, figures 8 and 9.

For curved edges drills, the back angle along the edge has relatively uniform measurements for different *Rx* radii of measurement cylinders.

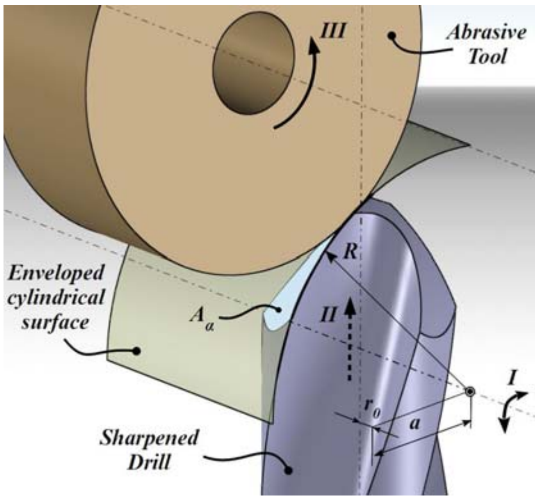

Fig. 8. *Sharpening layout for the curved edge drill*

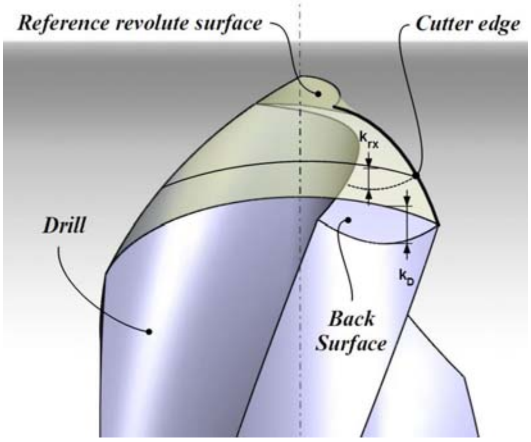

Fig. 9. *Defining the back surface's relieving*

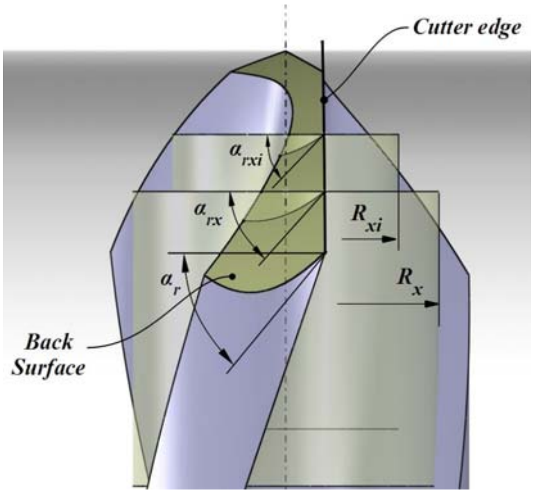

Fig. 10. *The size of back angles*

6. CONCLUSIONS

The method of analyzing the geometry of back surfaces for drills, with straight or curved edges, presented in this paper, was developed in the graphic design CATIA software. The method is characterized by the ability to rigorously model the shape of the back surface generated for different sharpening processes.

Using the specific environmental indications of the CATIA software, we can highlight the requirements imposed on a sharpening surface: the variation law of the back angle's size, along the main edge and ensuring the main back surface's relieving for the drill's cutter edge. The method is faster and highly intuitive in comparison with methods based on analytical description of surfaces.

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