

Hyperboloidal Sharpening Method for Multi-Flute Curved Edges Drills

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ABSTRACT

This paper presents an analytical model of a sharpening method for helical drill with curved edges, characterized by a main hyperboloidal shaped placing surface, with an edge with a fluctuating angle of incidence, decreasing along the cutting edge. Such a shape of the main cutting edge ensures an even, unitary energetic charge along the cutting edge. The analytical model of the cutting edge and of the shape of the back face is analyzed and conditioned to meet the minimal requirements of drills' sharpening process: the size of the back angle along the cutting edge, obtaining relieving of the main back face at a single positioning of the tool, in relation to the sharpening surface.

KEYWORDS: multi-edge helical drill, hyperboloidal sharpening, numerical modeling.

1. Introduction

A continuous path of research in the area of designing helical drills can be highlighted with the purpose of optimizing the geometrical parameters for the drill's cutting edge of the blade, Anish [1], [2] or the edge's shape, Fetecău [4], [5] that proposes a curved edge, also summarizing particular sharpening techniques. In the same sense, Dima [3], suggests a type of shape optimization for the curved edge, carrying out an energetic charge model of the cutting points and arriving, in the end, at an adequate shape from this point of view.

Analyses development for improving the main edge's shape has led to a spatial edge model.[3], [5], [6].

These new geometries require new sharpening procedures of the main back face, ensuring a growing variation law for the back angle, from the periphery towards the tool's axis, simultaneous with the decrease of the main angle of attack, from the tip of the tool towards its periphery [5], [7].

Also, a new method has to ensure a proper relieving of the main back face, from a single positioning of the drill on the sharpening device.

A new shape is suggested, following a sharpening outline with simple kinetics (a minimal number of moves) and one which allows rigorous rendering of the sharpening process.

2. The Fundamental Kinetics. The Back Face

In figure 1, the shape of the sharpening surface is presented – a hyperboloidal rotation surface – and the drill's position in relation to the sharpening surface.

The main cutting edge is resulted from the conjunction of the undercut surface (the helical drill's flute) with the sharpening surfaces. The main kinetics of the cutting process covers three moves:

I – the swing motion of the sharpened drill in relation to the straight generating line of the grinding wheel;

II – the feed motion of the sharpened drill along its own axis;

III – the cutting motion - the rotation of the grinding wheel around its own axis.

The active generating line of the grinding wheel is straight and belongs to a rotation surface exterior to it. The generating line is separated from the sharpened drill's axis and it is placed at the R_0 distance from the axis of the generated hyperboloid.

It is suggested a model for generating the back face of multi-edge helical drills (three-edged drills) after a hyperboloidal surface, in the sense that the back face of the main curved edge belongs to a hyperboloidal rotation surface – figure 2, generated, in the swing motion of the drill, in relation to the straight generated line of the grinding wheel.

It is accepted that, the hyperboloidal rotation surface is generated by a straight line that belongs to the reference system $X_1Y_1Z_1$ which has the following parametric equations, figure 2:

$$\Delta_{X_1Y_1Z_1} : \begin{cases} X_1 = u \cdot \sin \lambda; \\ Y_1 = 0; \\ Z_1 = u \cdot \cos \lambda. \end{cases} \quad (1)$$

with u variable parameter. In the rotating motion around the Z axis (Z – hyperboloid's axis), of variable parameter φ :

$$X = \omega_3^T(\varphi) \cdot X_1 - \begin{pmatrix} 0 \\ -R_0 \\ 0 \end{pmatrix} \quad (2)$$

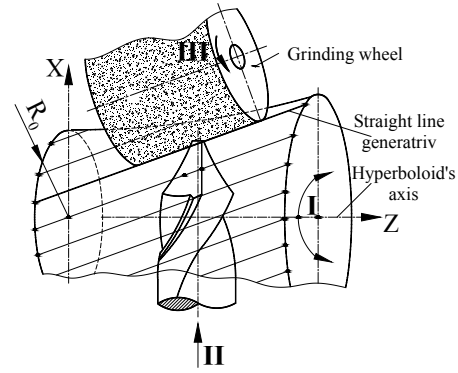


Fig. 1. The main kinetics of the hyperboloidal sharpening process

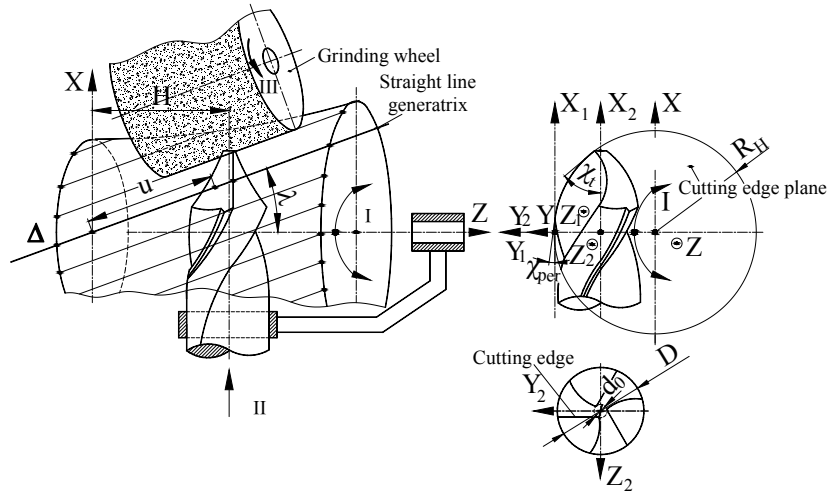


Fig. 2. The hyperboloidal back face

After substitution:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \cos \varphi & -\sin \varphi & 0 \\ \sin \varphi & \cos \varphi & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} u \cdot \sin \lambda \\ R_0 \\ u \cdot \cos \lambda \end{pmatrix} \quad (3)$$

with R_0 and λ - design values, the family of straight lines is generated – the hyperboloidal surface:

$$\begin{aligned} X &= u \cdot \sin \lambda \cdot \cos \varphi - R_0 \cdot \sin \varphi; \\ Y &= u \cdot \sin \lambda \cdot \sin \varphi + R_0 \cdot \cos \varphi; \\ Z &= u \cdot \cos \lambda. \end{aligned} \quad (4)$$

The (4) equations represent the analytical model of the setting surface of the drill's main edge with curved edges. The cutting edge of the main blade of the drill can be, depending on the acceptance conditions, a smooth edge belonging to a circle or to

an ellipse on the surface of the hyperboloid, or, also, a spatial curve belonging to the same surface, if the drill's flute shape can be achieved accordingly.

As a first solution, see [6], a circular shape is accepted as the shape of the cutting edge, shape that is resulted from the intersection of the rotation hyperboloid (4) with a plane perpendicular on the rotation axis, see figure 2. Thus, the cutting edge can be an arch belonging to radius R_H , the radius representing the transversal section of the hyperboloid.

3. The Shape of the Cutting Edge

For smooth planes - from (4),

$$Z = H \quad (5)$$

with H arbitrary variable determined by technological reasons according to the size of the sharpened drill's diameter, the restriction follows

$$H = u \cdot \cos \lambda, \quad (6)$$

see also figure 3, that determines the shape of the cutting edge C_H , as intersection of the $Z = H$ plane with the hiperboloidal surface:

$$C_H : \begin{cases} X = H \cdot \operatorname{tg} \lambda \cdot \cos \varphi - R_0 \cdot \sin \varphi; \\ Y = H \cdot \operatorname{tg} \lambda \cdot \sin \varphi + R_0 \cdot \cos \varphi; \\ Z = H. \end{cases} \quad (7)$$

In another way, the equations (7) represent the circle

$$X^2 + Y^2 = H^2 \cdot \operatorname{tg}^2 \lambda + R_0^2. \quad (8)$$

with the notation

$$H^2 \cdot \operatorname{tg}^2 \lambda + R_0^2 = R_H^2, \quad (9)$$

shape (8) represents the circle to which the cutting edge of the drill belongs.

$$X^2 + Y^2 = R_H^2. \quad (10)$$

The shape of the cutting edge is defined in correlation with the known geometric parameters of the edge: χ_t - the size of the maximum angle of attack, at the tip; χ_{per} - the size of the minimum angle of attack, at the periphery; α_D - the size of the back angle at the base of the drill.

The cutting edge's equations are put in relation to its own reference system, $X_2Y_2Z_2$, see figure 3, in which, the X_2 axis is the sharpened drill's axis, through the transformation:

$$X_2 = [X - b], \quad (11)$$

$$b = \begin{pmatrix} 0 \\ e \\ H - d_0 / 2 \end{pmatrix}, \quad (12)$$

with e - constructive constant, determined by the geometry imposed on the main cutting edge.

Thus, referring to the (7) shape, in the $X_2Y_2Z_2$ system, the cutting edge's equations become (13):

$$C_{H_{X_2Y_2Z_2}} : \begin{cases} X_2 = H \cdot \operatorname{tg} \lambda \cdot \cos \varphi - R_0 \cdot \sin \varphi; \\ Y_2 = H \cdot \operatorname{tg} \lambda \cdot \sin \varphi + R_0 \cdot \cos \varphi - e; \\ Z_2 = \frac{d_0}{2}. \end{cases} \quad (13)$$

4. The Variation Law for the Size of the Back Angle

The back angle is defined α_x in a plane parallel with the drill's axis, in the measuring plane - the perpendicular plane on the base constructive

plane, in the point considered on the cutting edge, figure 4.

The base plane, the plane that contains the considered point is in a point of the cutting edge and it is perpendicular to the direction of the cutting motion, (the speed's direction in the M point, in the rotation movement of the drill).

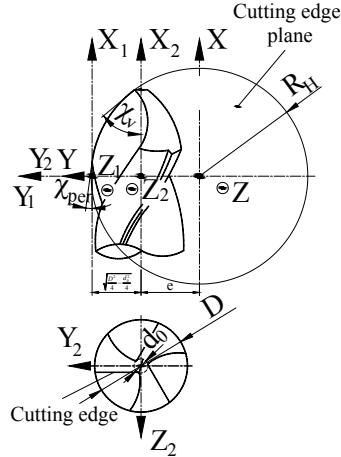


Fig. 3. The reference system for the cutting edge

In other words, with the figure 4 notations, the normal line to the measuring plane, in reality to the track of the measuring plane in the figure's plane, has the direction:

$$\vec{n}_{P_M} = -\cos \beta_x \cdot \vec{j} - \sin \beta_x \cdot \vec{k} \quad (14)$$

It is defined:

$$\beta_x = \arcsin \left[\frac{d_0}{2 \cdot r_x} \right]; \quad (15)$$

r_x - radius of the cilinder on which the M point is located, in which the setting angle is defined; d_0 - diameter of the drill's core.

The plane's equation P_M - parallel plane to the drill's axis (X_2 axis) is (16):

$$P_M = \left[Y_2 - \sqrt{r_x^2 - \frac{d_0^2}{4}} \right] \cdot \cos \beta_x + \left[Z_2 - \frac{d_0}{2} \right] \cdot \sin \beta_x = 0 \quad (16)$$

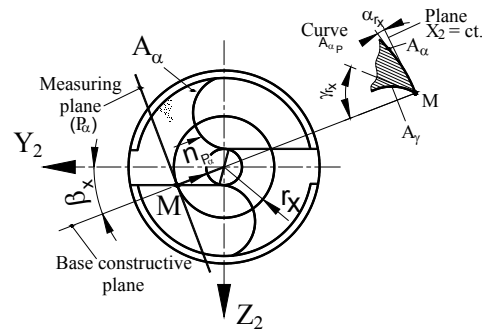


Fig. 4. The measuring plane

It can be defined, now, the intersection curve of the back face of the main cutting edge (hyperboloidal surface), see equations (4), with the measuring plane. The hyperboloidal surface is related to the $X_2Y_2Z_2$ system through the transformation:

$$\begin{pmatrix} X_2 \\ Y_2 \\ Z_2 \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} - \begin{pmatrix} 0 \\ e \\ -d_0/2 \end{pmatrix} \quad (17)$$

Thus, the equations of the hyperboloidal surface – forming the back face of the main curvilinear edge of the drill in the $X_2Y_2Z_2$ system have the configuration:

$$A_\alpha : \begin{cases} X_2 = u \cdot \sin \lambda \cdot \cos \varphi - R_0 \cdot \sin \varphi; \\ Y_2 = u \cdot \sin \lambda \cdot \sin \varphi + R_0 \cdot \cos \varphi - e; \\ Z_2 = u \cdot \cos \lambda + d_0/2, \end{cases} \quad (18)$$

with u and φ as the independent variable parameters. The sizes R_0 , e , λ , d_0 are definable as constructive sizes (technological constants).

The intersection of surfaces – the measuring plane (16) and the hyperboloid (18) – both defined in the same system of reference, leads to the condition (19):

$$\begin{aligned} & \left[u \cdot \sin \lambda \cdot \sin \varphi + R_0 \cdot \cos \varphi - \right. \\ & \left. - e - \sqrt{r_x^2 - \frac{d_0^2}{4}} \right] \cdot \cos \beta_x + \\ & + u \cdot \cos \lambda \cdot \sin \beta_x = 0. \end{aligned} \quad (19)$$

Fundamentally, the condition (19) establishes a geometric space in the $X_2Y_2Z_2$ system, expressed through an algebraic connection between the parameters u and φ .

Condition(19) can be expressed as such:

$$u = \frac{\left[R_0 \cdot \cos \varphi - e - \sqrt{r_x^2 - \frac{d_0^2}{4}} \right] \cdot \cos \beta_x}{\sin \lambda \cdot \sin \varphi \cdot \cos \beta_x + \cos \lambda \cdot \sin \beta_x}, \quad (20)$$

The ensemble of equations created from the setting surface (18) and the condition (19) is the equations of the intersection curve of the setting surface with the measuring plane A_{α_p} (21):

$$A_{\alpha_p} : \begin{cases} X_2 = \frac{\left[R_0 \cdot \cos \varphi - e - \sqrt{r_x^2 - \frac{d_0^2}{4}} \right]}{\sin \lambda \cdot \sin \varphi + \cos \lambda \cdot \operatorname{tg} \beta_x} \cdot \sin \lambda \cdot \cos \varphi - R_0 \cdot \sin \varphi; \\ Y_2 = \frac{\left[R_0 \cdot \cos \varphi - e - \sqrt{r_x^2 - \frac{d_0^2}{4}} \right]}{\sin \lambda \cdot \sin \varphi + \cos \lambda \cdot \operatorname{tg} \beta_x} \cdot \sin \lambda \cdot \sin \varphi + R_0 \cdot \cos \varphi - e; \\ Z_2 = \frac{\left[R_0 \cdot \cos \varphi - e - \sqrt{r_x^2 - \frac{d_0^2}{4}} \right]}{\sin \lambda \cdot \sin \varphi + \cos \lambda \cdot \operatorname{tg} \beta_x} \cdot \cos \lambda + d_0/2. \end{cases} \quad (21)$$

Evidently, it is most necessary for the β_x angle to meet the requirement:

$$\beta_x < \frac{\pi}{2}. \quad (22)$$

Curve (21) is, evidently, a smooth curve, but the plane in which this is defined is not parallel to one of the reference planes. The back angle in M point on the cutting edge is defined between the tangent line (21), in the point on the cutting edge, the direction of the cutting motion (here a perpendicular plane on the X_2 axis, that contains the same M point – figure 4),

$$X_2 = \text{constant}. \quad (23)$$

If marked with $X'_{2_\varphi}, Y'_{2_\varphi}, Z'_{2_\varphi}$ - partial derivatives of equations (21), representing the direction parametres of the tangent line to this A_{α_p} curve, then the setting angle is defined as:

$$\cos \alpha_x = \frac{X'_{2_\varphi}}{\sqrt{\left(X'_{2_\varphi}\right)^2 + \left(Y'_{2_\varphi}\right)^2 + \left(Z'_{2_\varphi}\right)^2}} \quad (24)$$

The partial derivatives are defined (25):

$$\begin{aligned} X'_{2_\varphi} &= u'_\varphi \cdot \sin \lambda \cdot \cos \varphi - \\ & - u \cdot \sin \lambda \cdot \cos \varphi - R_0 \cdot \cos \varphi; \\ Y'_{2_\varphi} &= u'_\varphi \cdot \sin \lambda \cdot \sin \varphi + \\ & + u \cdot \sin \lambda \cdot \sin \varphi - R_0 \cdot \sin \varphi; \\ Z'_{2_\varphi} &= u'_\varphi \cdot \cos \lambda. \end{aligned} \quad (25)$$

The partial derivative is defined:

$$u'_\varphi = \frac{du}{d\varphi}, \text{ see (20), that is} \quad (26)$$

$$u'_\varphi = \frac{-R_0 \cdot \sin \varphi \cdot [\sin \lambda \cdot \sin \varphi + \cos \lambda \cdot \operatorname{tg} \beta_x] - R_0 \cdot \cos \varphi - e - \sqrt{r_x^2 - \frac{d_0^2}{4}} \cdot \cos \beta_x \cdot \sin \lambda \cdot \cos \varphi}{[\sin \lambda \cdot \sin \varphi + \cos \lambda \cdot \operatorname{tg} \beta_x]^2} \quad (27)$$

The geometric elements that determine the shape of the rotation hyperboloid, as they were previously defined, are:

- the position of the sharpened drill's axis, measured along the axis of the hyperboloidal surface, in relation to the minimal crossing section of the hyperboloid, H ;
- the size of the offsetting of the circle origin, to which the cutting edge belongs, in relation to the drill's axis, e ;
- the size of the radius of the minimal transversal cut of the hyperboloid, constituent of the setting surface, R_0 ;
- the inclination angle of the hyperboloidal surface generator in relation to the hyperboloid's axis, λ .

Determination of the size of these parameters is made in relation to:

- the geometry of the shape of the cutting edge (the variation limits of the main angle of attack);
- the size of the back angle at the drill's periphery;
- ensuring relieving of the back face, at a single positioning of the sharpened drill in relation to the hyperboloidal surface.

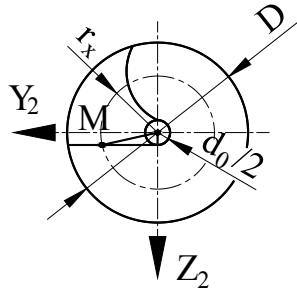


Fig. 5. The relieving curve

5. Relieving of the Back Face

The relieving of the back face is defined in connection with the intersection of the back face (hyperboloidal surface) with a coaxial cylinder unto the sharpened drill, figure 5.

Thus, for the cylinder with the radius r_x , the equation for the revolving cylinder is defined:

$$Y_2^2 + Z_2^2 = r_x^2, \quad r_x - \text{variable}, \quad (28)$$

$$r_x \in \left[\frac{d_0}{2}, \frac{D}{2} \right]. \quad (29)$$

If the equation system for the back face (see (18)) is accepted, then, the condition of the intersection of the two surfaces, the cylinder and the hyperboloid, is obtained taking into consideration (28) and (18) in the format:

$$\begin{aligned} & [u \cdot \sin \lambda \cdot \cos \varphi - R_0 \cdot \sin \varphi]^2 + \\ & + [u \cdot \cos \lambda + d_0 / 2]^2 = r_x^2. \end{aligned} \quad (30)$$

Condition (30) has the significance of a second degree equation in the u variable (31):

$$\begin{aligned} & u^2 [\sin^2 \lambda \cdot \cos^2 \varphi + \cos^2 \lambda] + \\ & + 2u [-R_0 \cdot \sin \lambda \cdot \sin \varphi \cdot \cos \varphi + \\ & + d_0 / 2 \cdot \cos \lambda] + \\ & + [R_0^2 \cdot \sin^2 \varphi - d_0^2 / 4 - r_x^2] = 0. \end{aligned} \quad (31)$$

By solving equation (31) the smallest solution for u is accepted.

Relieving is defined as representing the difference between the X_2 coordinates of the point on the cutting edge and the rest of the points belonging to the surface.

Relieving is considered fulfilled, if for all the points of the back face, found at the r_x distance from the drill's axis, the following condition is met:

$$X_{2_M} > X_{2_{M_i}}, \quad (32)$$

M – is the considered point on the tool's edge.

Assuring the condition of a certain variation law of the size of attack angle, along the main edge of the drill, the size of the R_H and the e parameters are determined.

Thus, see figure 3, from the system:

$$\begin{cases} R_H \cdot \cos \chi_{per} = e + \sqrt{r_x^2 - \frac{d_0^2}{4}}; \\ e = R_H \cdot \cos \chi_t. \end{cases} \quad (33)$$

It results the calculation form:

$$R_H = \frac{\sqrt{\frac{D^2}{4} - \frac{d_0^2}{4}}}{\cos \chi_{per} - \cos \chi_t}; \quad (34)$$

$$e = \frac{\sqrt{\frac{D^2}{4} - \frac{d_0^2}{4}}}{\cos \chi_{per} - \cos \chi_t} \cdot \cos \chi_t. \quad (35)$$

Out of the relation

$$R_H^2 = H^2 \cdot \text{tg}^2 \lambda + R_0^2 \quad (36)$$

a connection is created among the hyperboloidal surface parameters H , λ și R_0 .

6. Numerical Applications

A numerical solution is proposed to resolve problems pertaining to the sharpening process, checking the relieving of the back face and determining the variation law of the setting angle's size along the main edge, using the CATIA facilities.

Based on the previously presented definitions, for a drill and a sharpening surface having the following properties:

$D = 20 \text{ mm}$; $\chi_{per} = 5^\circ$; $\chi_t = 60^\circ$; $R_0 = 4 \text{ mm}$; $\lambda = 15^\circ$, in figure 6, the shape of the relieving curves, in the perpendicular planes on the drill's axis is presented.

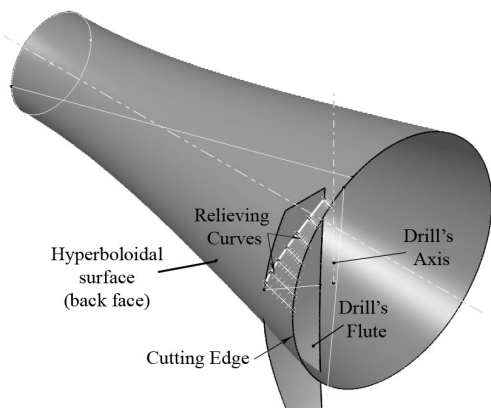


Fig. 6. The shape of the relieving curves

It is obvious that in relation to the trajectory of the points on the edge, in the main cutting motion (the drill's rotation around its own axis), for all point on the main edge, beveling of the setting surface is assured.

In figure 7, the cylindrical cuts coaxial with the drill and the intersected curves with the back face are presented, which determine the size of the back angle, on the edge's points, like the angle created between the tangent to the intersection line of the setting point with the cylindrical surface (the surface on which the drill's cutting movements take place), the main motion and the feed motion (along the drill) and the plane perpendicular on the drill's axis.

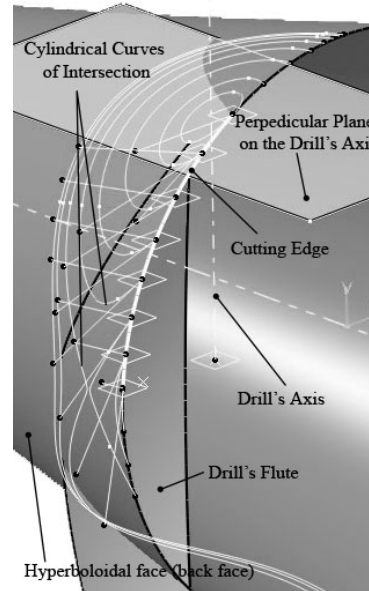


Fig. 7. Cylindrical cuts and the intersection curves with the drill's setting surface

In the figure, the back face's model is presented (the hyperboloidal surface), intersection curves with the cylinder coaxial with the drill and the perpendicular plane, in one of the edge's points on the drill's axis.

In figure 8 and 9 the variation law of the back angle's size is shown, along the main drill's edge.

In table 1, are presented the values of r_x and α .

Table 1. The r_x and α values

r_x [mm]	α [°]	r_x [mm]	α [°]
9.54	25.781	7.253	31.567
9.266	26.345	6.225	35.338
8.788	27.4	5.056	41.283
8.113	29.065	3.802	51.577

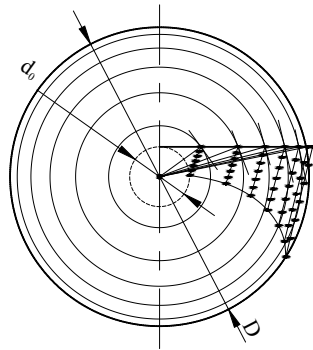


Fig. 8. The relieving curves

7. Conclusions

The proposed hyperboloidal method of sharpening creates a variable angle of attack along the main edge, the shape of the edge being a sector, thus, ensuring a constant unitary energetic charge in all the points on the edge. The positioning of the drill's axis allows the production of the angle of attack along the main edge, with regard to the limiting-conditions of the maximum (χ_t) and the minimum (χ_{per}) sizes.

The relieving conditions of the entire main back face are ensured for a single positioning of the drill in relation to the back face.

The back angle has high value along the main cutting edge, thus ensuring a well functioning angle of attack.

Although the size of the back angle at the periphery of the tool is wider resulting in a narrow cutting edge, the detached fragment is thin and thus the drill's cutting action is adequate.

The kinetics of the process is simple with a small number of necessary moves.

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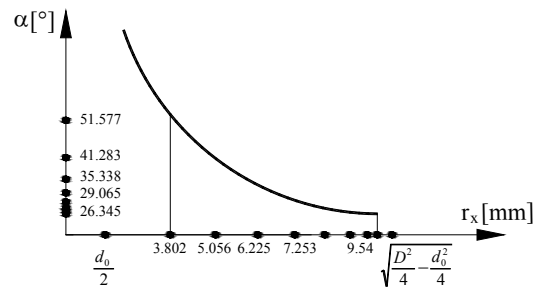


Fig. 9. Variation law for the setting angle's size

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Procedeu de ascuțire hiperboloidală a burghiilor cu tășuri curbe multităis

Rezumat

Lucrarea prezintă un model analitic al unui procedeu de ascuțire a burghiilor elicoidale cu tășuri curbe caracterizat prin aceea că suprafața de așezare principală este de formă hiperboloidală cu un tăș cu unghi de atac variabil, descrescător în lungul muchiei de așchiere. O astfel de formă a muchiei de așchiere principală asigură o încărcare energetică unitară uniformă în lungul muchiei de așchiere. Modelul analitic al muchiei de așchiere și a formei suprafeței de așezare este analizat din condițiile îndeplinirii cerințelor minime ale unui procedeu de ascuțire a burghiilor: asigurarea mărimii unghiului de așezare în lungul muchiei de așchiere, realizarea detalonării suprafeței principale de așezare la o singură poziționare a sculei în raport cu suprafața de ascuțire.