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Developing a Methodology for Calculating the Working Angles of Cutting Tools with Replaceable Cutting Inserts

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***Abstract*— Taking into account the kinematics of the cutting process and the trajectory of the relatively working movement is described trajectory of an arbitrary point of the active part of the cutting edge of a specific tool.**
The rake face and the clearance angle face of a tool are described and also the surface of the cutting. Mathematical dependence for the determination of direction of flow of the chip is obtained.

The obtained results are used for: design of cutting tools; analysis of method of machining and developing a strategy for the chip breaking.

***Index Terms*— Cutting tools; Replaceable cutting inserts**

I. Introduction

In determining the geometric parameters, the cutting tool is considered as a spatial body in a resting state [1-5]. For a base point for formulating definitions of static parameters appear [3, 6]:

- Technological design of the tool;
- Opportunity to control the tool as a production site.

Depending on the complexity of the principal kinematics scheme and the ratio between the linear and angular velocities of the individual movements, they may be varied in both the character and complexity of the trajectory of the relative motion of the instrument and the workpiece [5,7]. In general case, the real geometrical parameters during operation of the tool are not identical to the static either in magnitude or the direction of their dimension [8,9]. That is why it is necessary to establish a new system for determining the kinematic geometric parameters, considering the instrument not as a space geometric body in a resting position, but as an object carrying out a certain work movement on the work surface of the workpiece.

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II. Methodology of calculating the working angles of cutting tools with removable cutting inserts

A. Nomenclature

$\alpha_к$	kinematic clearance angle, [°]
s	feed, [mm/rev]
R	radius of treated surface (identical with radius of circular cylinder), [mm]
ω	angle of elevation of the helical trajectory of the working movement, [°]
α_0	rake angle, [°]
λ_s	tool cutting edge inclination, [°]
XYZ	major coordinate system
x, y, z	coordinates of major coordinate system, [mm]
X_0, Y_0, Z_0	coordinates of point M, [mm]
S	major cutting edge, [mm]
α_{fe}	working side clearance angle, [°]
Ve	actual cutting speed, [m/min]
ε	corner angle, [°]
κ_r	tool cutting edge angle, [°]
θ	angle of leakage of the chip, [°]
γ_{oe}	working rake angle, [°]
Aγ	face
λse	working angle of tool cutting edge inclination, [°]
λ`se	projection of working angle of tool cutting edge inclination, [°]
α_{oe}	working clearance angle, [°]
γ_o	rake angle, [°]
h	the position of the active cutting edge of the insert relative to the tool axis of rotation, [mm]

For a base point for determining the geometric parameters in the cutting process appear:

- The trajectory of the relative displacement of the cutting element of the instrument relative to the surface of the workpiece;
- The regularity of the deformation process during the chip forming and the direction of leakage of the separated chip on the contact surface of the front surface of the tool.

A fundamental requirement to the design of the tool is the ability of all the points on its major flank to perform unobstructed, in the cutting process, working movement on the trajectory of the relative displacement predetermined by the adopted principle kinematic cutting scheme [9].

Basic geometric parameter predetermining the performing of the unobstructed working movement of the tool in the cutting process is the clearance angle. Determining the clearance angle in working process is directly related to the trajectory of relative working movement of the tool and the concept of simple and complex work movement. Expressing the real magnitude of the space between the major flank of the tool moving in the cutting process and the cutting surface of the workpiece (the workpiece).

For tools with complex work movement, a total force load is formed on the basis of [8-10]:

- Effort from deformation of the metal removed in the form of chip;
- Friction forces of the separated chip at the contact surface of the face;
- Friction forces between the cutting surface and the contact surface of the clearance angle;
- Effort from deformation ;
- Effort from deformation of the separated layer of metal from the unsharpened part of the cutting edge of the tool.

For tools with a helical trajectory of relative work movement result of the combination of one main rotational and auxiliary rectilinear motion, the kinematic clearance angle $\alpha_к$ is determined using Fig. 1 and the following dependence:

$$\alpha_k = arctg\frac{s}{2.\pi.R} = arctg\omega \tag{1}$$

The dependency analysis shows that for tools with helical working movement the kinematic clearance angle is a variable magnitude whose value depends on the distance between the considered point and axis of rotation.

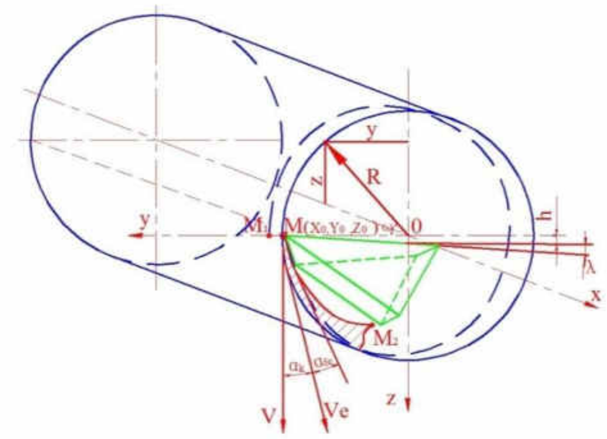


Fig. 1 Determining of kinematic clearance angle and clearance angle of the tool.

For the considered metal cutting tools with a complex working movement each point M of the cutting edge describes helical line relative the axis of the workpiece which represent a complex spatial trajectory of movement of the points on the major flank of the tool to the surface of the cutting.

The forming line of the cutting surface is identical with the trajectory of the relative movement of the examined point M, and the position of the cutting edge.

According to Fig. 1 the equation of the line on which the vector Ve lies at the nominal cutting speed, at any point on the cutting edge, point M (X_0, Y_0, Z_0) adopts the following form:

$$\frac{y - Y_0}{R.\sin(\omega)} = \frac{z - Z_0}{R.\cos(\omega)} \tag{2}$$

The kinematic clearance angle locked between the tangent to the helical trajectory of the relative movement in the pt. M (X_0, Y_0, Z_0) and the direction of the V vector of the nominal cutting speed is determined by the following dependence:

$$\cos\alpha_k = \frac{\frac{s}{2.\pi} + R^2.\sin^2\omega + \cos^2\omega}{\sqrt{(\frac{s}{2.\pi})^2 + R^2.\sin^2\omega + R^2.\cos^2\omega}.\sqrt{R^2.\sin^2\omega + R^2.\cos^2\omega}} \tag{3}$$

$$\cos\alpha_k = \frac{2.\pi.R}{\sqrt{(2.\pi.R)^2 + s^2}} = \cos(\omega) \tag{4}$$

In unilaterally cutting tools having to trajectory of the relative working movement helical line, the kinematic clearance angle is equal to the rise of the helical trajectory.

The angle locked between the tangent to the helical trajectory of the relative work movement and the tangent to the intersection line of the major flank and a cylinder surface is the working side clearance angle of the tool during the cutting process:

$$\alpha_{fe} = \frac{\frac{R.S}{2\pi.\sin\lambda_s}(\cos\lambda_s.\sin\omega - tg\alpha_0\cos\omega) + R^2.\sin^2\omega + R^2.\cos^2\omega}{\sqrt{\frac{R^2}{\sin^2\lambda_s}.(\cos\lambda_s.\sin\omega - tg\alpha_0.\cos\omega)^2 + R^2}.\sqrt{\frac{S^2}{(2.\pi)^2} + R^2}}.\frac{\sin\lambda_s.(x - X_0)}{R(\cos\lambda_s.\sin\omega - tg\alpha_0.\cos\omega)} \tag{5}$$

$$\alpha_{fe} = -\frac{y - Y_0}{R.\sin\omega} = \frac{z - Z_0}{R.\cos\omega} \tag{6}$$

To determine the chip leak angle, analytical dependencies are required to determine of:

- The directional cosines of the vector of the actual cutting speed Ve.
- The directional cosines of the major cutting edge S.

A single-sided drill with one disposable carbide insert and a positive angle of inclination of the major cutting edge in the XYZ spatial coordinate system is being considered (Fig. 2). The X axis coincides with the axis of rotation of the workpiece and the vector of the actual cutting speed Ve with the applied point M (X_0, Y_0, Z_0) crosses the plane XY at point M_2 and forms the angles α_1, β_1, γ_1 with the axes X, Y and Z, the magnitudes of which are expressed by the dependencies:

$$\begin{cases} \cos\alpha_1 = \sin\omega \\ \cos\beta_1 = \cos\omega.\sin\varepsilon \\ \cos\gamma_1 = \cos\omega.\cos\varepsilon \end{cases} \tag{7}$$

The major cutting edge S forms, with the axes of the XYZ coordinate system, the angles α_2, β_2 and γ_2 (Fig. 3), whose magnitudes are determined by the following dependencies:

$$\begin{cases} \cos\alpha_2 = \cos\chi_r.\cos\lambda_s \\ \cos\beta_2 = \sin\chi_r.\cos\lambda_s \\ \cos\gamma_2 = \cos\lambda_s \end{cases} \tag{8}$$

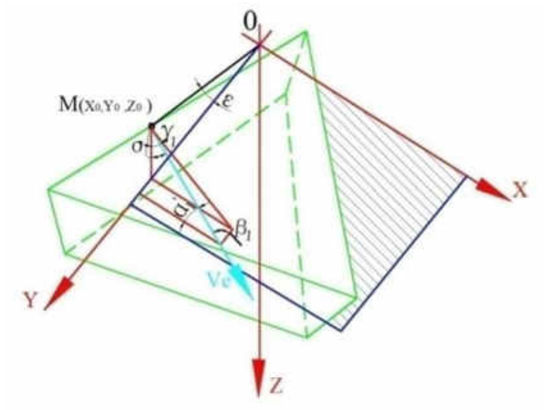


Fig. 2 Determining of the directional cosines of the vector of the actual cutting speed Ve.

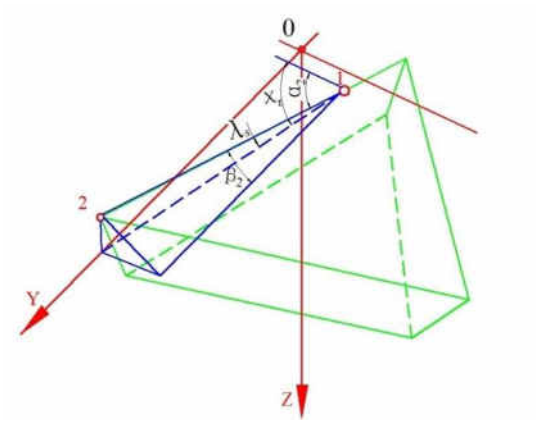


Fig. 3 Determining of directional cosines of the major cutting edge.

The dependence of determining the angle of leakage of the chip θ takes the form:

$$\sin\theta = \cos(\kappa_r).\cos(\lambda_s).\sin(\omega) + \sin(\kappa_r).\cos(\lambda_s).\cos(\omega).\sin(\varepsilon) + \sin(\lambda_s).\cos(\omega).\cos(\varepsilon) \quad (9)$$

To determine the working rake angle γ_{oe} of the tool it is necessary to use:

- the equation of a plane perpendicular to the vector of the actual cutting speed Ve in pt. M (X_0, Y_0, Z_0) from the major cutting edge of the tool;
- the equation of the tangent to the contact surface on the face Aγ of the tool and coinciding with the direction of leakage of the chip.

The directional cosines of the vector of the actual cutting speed Ve in pt. M (X_0, Y_0, Z_0) are determined by the following dependencies:

$$\left|\begin{aligned}\cos\alpha_2 &= \cos\kappa_r.\cos\lambda_s\\ \cos\beta_2 &= \sin\kappa_r.\cos\lambda_s\\ \cos\gamma_2 &= \cos\lambda_s\end{aligned}\right. \quad (10)$$

The equation of the tangent to the helical trajectory of the complex spatial working movement is the following:

$$\frac{x - X_0}{\sin(\omega)} = \frac{y - Y_0}{\cos(\omega).\sin(\varepsilon)} = \frac{z - Z_0}{\cos(\omega).\cos(\varepsilon)} \quad (11)$$

The equation of the plane perpendicular to the vector Ve in pt. M (X_0, Y_0, Z_0) is of the type:

$$\sin(\omega).(x - X_0) + \cos(\omega).\sin(\varepsilon).(y - Y_0) + + \cos(\omega).\cos(\varepsilon).(z - Z_0) = 0 \quad (12)$$

The most probable direction of chip flow is at a distance from the perpendicular to the major cutting edge by an angle equal to the working angle of the inclination of the major cutting edge S, measured in the plane of the face of the tool Aγ. The projection of the angle λse in the XY plane is determined by the dependence:

$$tg(\grave{\lambda}_{se}) = \frac{tg(\lambda_{se})}{\cos(\gamma_0)} \quad (13)$$

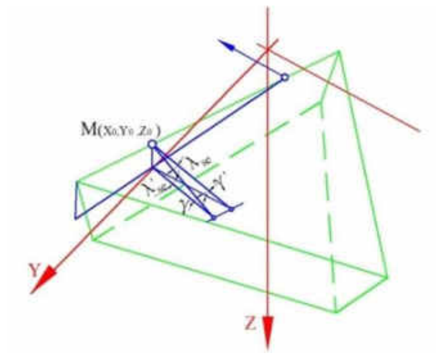


Fig. 4 Determining of direction of chip flow.

For determining the angle of the leakage of the chip at considered trajectory of relative working movement and a positive angle of the inclination of the major cutting edge S is used Fig. 4.

In the direction of actual chip flow, the rake angle γ′ < γ.

$$\left|\begin{aligned}\sin\gamma' &= \sin\gamma_0.\cos\lambda_{se}\\ \cos\gamma' &= \sqrt{1 - \sin\gamma_0.\cos^2\lambda_{se}}\end{aligned}\right. \quad (14)$$

The projection of the straight line, which coinciding with the direction of the actual chip flow on the face of the tool in the plane XY, forms with the feeding vector s an angle χ_r + λ`se.

$$\left|\begin{aligned}\cos\alpha_3 &= \sin(\lambda_s + \lambda'_{se}).\sqrt{1 - \sin^2\gamma_0.\cos^2\lambda_{se}}\\ \cos\beta_3 &= \cos(\lambda_s + \lambda'_{se}).\sqrt{1 - \sin^2\gamma_0.\cos^2.\lambda_{se}}\\ \cos\gamma_3 &= \sin\gamma_0.\cos\lambda_{se}\end{aligned}\right. \quad (15)$$

The equation of the straight is of the type:

$$\frac{x - X_0}{\sin(\lambda_s + \lambda'_{se}).\sqrt{1 - \sin^2 \gamma_0 . \cos^2 \lambda_{se}}} = \frac{y - Y_0}{\sin(\lambda_s + \lambda'_{se}).\sqrt{1 - \sin^2 \gamma_0 . \cos^2 \lambda_{se}}} = \frac{z - Z_0}{\sin \gamma_0 . \cos \lambda_{se}} \quad (16)$$

The working rake angle γ_{oe} at unilaterally cutting tools is expressed by dependence:

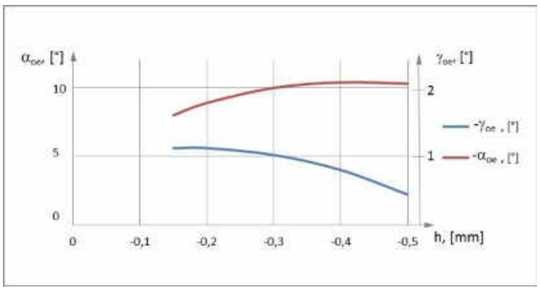
$$\sin \gamma_{oe} = \sqrt{1 - \sin^2 \gamma_0 . \cos^2 \theta} . \left(\sin(\lambda_s + \lambda'_{se}). \sin \omega + \cos(\lambda_s + \lambda'_{se}). \cos \omega . \sin \varepsilon\right) + \sin \gamma_0 . \cos \theta . \cos \omega . \cos \varepsilon \quad (17)$$

The proposed dependencies for α_{oe}, γ_{oe} and θ allow to model the operation of different tools and the spatial arrangement of their cutting elements. Knowing the equations of the trajectories of the movements for the different treatments, it is possible to conclude about the working angles at each point of the cutting edge.

III. Results

A tool for drilling holes Ø26 mm, working by the method of dividing the metal cutting layer, is subjected to a survey of geometrical parameters.

The most significant influence on the clearance angle variation, which determines the working efficiency of the instrument, is the parameter "h". This parameter determines the position of the active cutting edge of the insert relative to the tool axis of rotation (Fig. 5). The central insert of the drills with interchangeable insert can only be placed under the axis at a distance of not more than 0.4 mm. Otherwise, breakage of the cutting wedge occurs due to cutting speeds close to "0" m/min.



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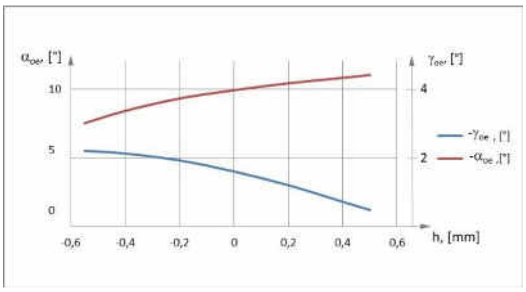
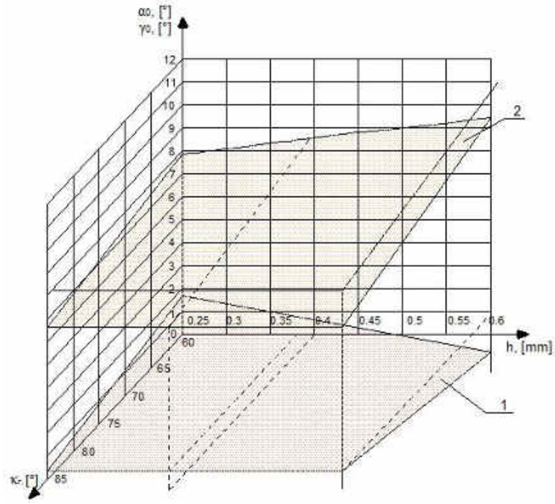


b

Fig. 5 Changing of working angles of drills with disposable carbide inserts.

(a) central cutting insert; (b) peripheral cutting insert

The spatial diagrams shown in Fig. 6 and Fig. 7 give a visual idea of the influence of the other geometric parameters defining the construction.



1 – change of rake angle γ_0; 2 – change of clearance angle α_0

Fig. 6 Change of working angles depending on the distance (h) and the tool cutting edge angle (χ_r).

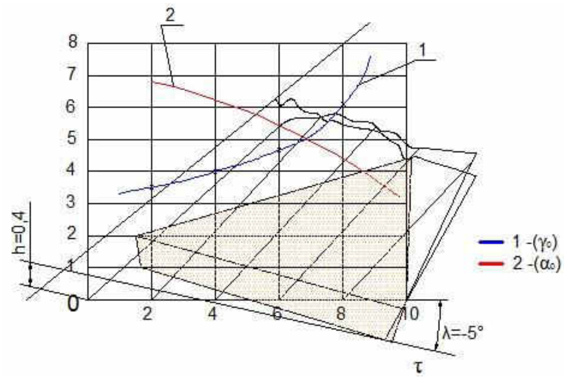


Fig. 7 Dependence between working angles of drills with disposable carbide insert, tool cutting edge inclination λ_s and the distance (h).

IV. Conclusion

An approbation of the developed calculation methodology is conducted and the modifications of the above mentioned working angles, their relation with the static geometric parameters and their change along the length of the cutting edge are shown.

The developed methodology allows to calculate the working angles in areas with a minimum cutting speed converging to "0" as it is at the center of a tool for machining holes. Also it allows to solve the following tasks of the designing of the cutting tools with a replaceable cutting part.

- to determine the spatial location of the insert places on the tool shank to provide a rational working geometry;
- to avoid areas from the active cutting edges of the tool where there would be unfavorable cutting and friction conditions;
- to determine the direction of the chip flow that would ensure its reliable breakage and transportation in open "V" grooves (especially for collapsible drills).

The developed mathematical model is easily adapted to the creation of programs for automation design of collapsible tools with replaceable cutting part.

Development includes contributions in the part of the designing of the cutting part of collapsible tools and solving of forward and inverse problems at determining rational cutting geometry

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