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GEOMETRY ANALYSIS OF STRAIGHT FLUTED TAPS

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Abstract: *The paper presents cutting tools geometry analysis of the active part of straight fluted taps. In addition to setting the analytical models, the taps are modeled in Autodesk Inventor CAD package with main parameters from external database. The geometry of the cutting tool is defined in detail in the geometry system, which includes a set of geometric parameters that determine the absolute and relative positions of all elements in machining system. This system includes all the parameters that determine the geometric accuracy of machines, tools and fixtures, as well as initial indicators of quality. Surfaces, cutting edges and tool angles, as a set of geometric elements with certain relations, define the geometry of the cutting tool. To derive the relation between the angles that define the geometry of the tools, the transformation matrix for coordinate systems of taps is defined, using the conventions for their description and representation which are used in problems of the solid modeling, i.e. computer graphics. In this way we can detect the influence of geometry on the main process factors: friction and wear between the tool and the chip, tool and part, tool life, the dynamic stability of a machining system, temperature and heat balance in the cutting zone, chip shape, surface finish, and others.*

Keywords: tap, cutting tools geometry, tool angles, CAD

1. INTRODUCTION

Metal cutting is one of the most important methods of removing material in the production of mechanical components. This treatment identifies the major problem areas and relates observed performance to fundamentals of physics, chemistry, materials behavior, and the engineering sciences of heat transfer, solid mechanics, and tribology [1, 4].

Cutting processes are extremely complex largely due to the fact that two basic operations occur simultaneously in close proximity with strong interaction: large strain plastic deformation in a zone of concentrated shear, material transport along a heavily loaded region of relative motion between chip and tool [1].

All cutting operations share the same principles of mechanics of cutting, but their geometry and kinematics are different. The first step in prediction of forces acting on a cutting tool is to consider a relatively simple orthogonal cutting process in which the cutting edge is perpendicular to the cutting speed and the deformation occurring in the plane, in order to continue to use the results of this analysis as a base for the development of a much more general case of oblique cutting where edge is angled to the cutting speed [4].

Tapping is a common operation used to produce internal screw threads in the predrilled hole with special tool, named tap. This is one of the more demanding machining processes.

Figure 1 shows the layout of machine taps M10 and M8.

Fig. 1. Machine taps (HSS-E, EMo5Co5)

2. STRAIGHT FLUTED TAPS GEOMETRY

The tool-in-hand and the tool-in-use reference system of planes can be defined for any tool. Tool-in-hand geometry includes a set of geometric elements, which are defined through the tool drawing, used in manufacturing, sharpening or measurement the tool. Tool-in-use geometry works with real or effective geometric elements of cutting tools, which appear in the cutting operations [2].

The figure 2 shows the tool-in-hand and the tool-in-use geometry of cutting tool part of machine tap with three straight flute, with nominal diameter ***D***, tool back rake γ_p and tool cutting edge angle κ_r, at selected point **0** on major cutting edge.

Projection of major cutting edge is shown in the plane P_r which is normal to cutting speed v at selected point.

Assumed working plane P_f contains cutting speed and feed speed. The cutting edge is approximately a straight line due to the small length of cut and rake angle. The cutting edge is inclined at approximately the chamfer angle κ_r, to the plane P_f as shown in the plane P_r.

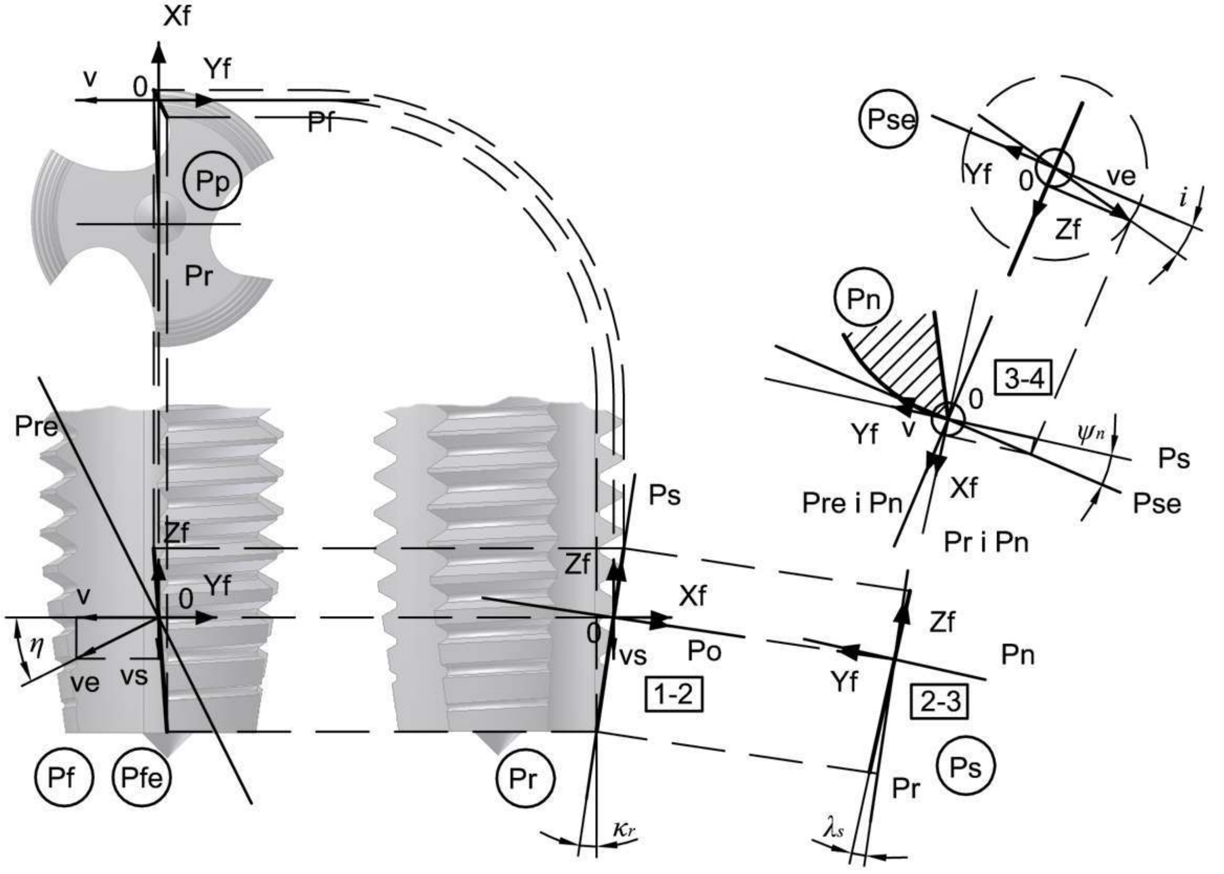


Fig. 2. Tool-in-hand and the tool-in-use geometry of machine tap.

Conventions for the description and presentation of the coordinate system and the indexing system of the transformations are from theory of computer graphics and modeling systems of solids, and are also used in robot manipulation problems.

An arbitrary point in the space P, can be presented with the position vectors with respect to a variety of coordinate systems, so for coordinate systems in which the origin coincides:

$$ {}^1\mathbf{p}={}^1_2R\cdot{}^2\mathbf{p}\ \text{, then}\ {}^2\mathbf{p}={}^1_2R^{-1}\cdot{}^1\mathbf{p}={}^1_2R^{T}\cdot{}^1\mathbf{p}\ , $$

because the inverse of a rotation matrix, R, is the same as its transposed matrix.

Based on figure 2, switch from the tool-in-hand coordinate system “f” defined with the basic planes P_r, P_f and P_p, labeled as "1“, into the tool-in-use system "4" defined with planes P_n, P_{se} and their normal plane that contains intersection $P_{re}\cap P_n$, requires three rotation matrix.

$$ {}^1_2R = R_{y,\kappa_r} = \begin{bmatrix} \cos\kappa_r & 0 & \sin\kappa_r \\ 0 & 1 & 0 \\ -\sin\kappa_r & 0 & \cos\kappa_r \end{bmatrix}, $$

$$ {}^2_3R = R_{x,\lambda_s} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\lambda_s & -\sin\lambda_s \\ 0 & \sin\lambda_s & \cos\lambda_s \end{bmatrix}, $$

$$ {}^3_4R = R_{z,\psi_n} = \begin{bmatrix} \cos\psi_n & -\sin\psi_n & 0 \\ \sin\psi_n & \cos\psi_n & 0 \\ 0 & 0 & 1 \end{bmatrix}, $$

where κ_r denotes the chamfer angle, λ_s is the angle of inclination and ψ_n is the angle between the cutting edge planes in tool-in-hand (P_s) and tool-in-use (P_{se}) geometry, measured in the normal plane P_n.

Coordinates of the end point of the resultant cutting velocity vector v_e in the first (plane P_f) and last coordinate system (plane P_{se}) according to figure 2, are known:

$$ {}^1\mathbf{p} = -v_e\begin{bmatrix}0 & \cos\eta & \sin\eta\end{bmatrix}^{\mathrm{T}} $$

$$ {}^4\mathbf{p} = -v_e\begin{bmatrix}0 & \cos i & -\sin i\end{bmatrix}^{\mathrm{T}}, $$

where η represents the resultant cutting speed angle and i is the oblique angle. From the expression:

$$ {}^1\mathbf{p}={}^1_2R\cdot{}^2_3R\cdot{}^3_4R\cdot{}^4\mathbf{p} $$

we obtain the unknown angles:

$$ tg\psi_n = \frac{tg\eta\sin\kappa_r}{\cos\lambda_s + tg\eta\cos\kappa_r\sin\lambda_s} $$

Rake angle, γ_{n0}, in the normal plane P_n, at selected point 0 on major edge is defined according to the figure 2, from the expression:

$$tg\gamma_{n0} = tg\gamma_{p0}\frac{\cos\lambda_s}{\cos\kappa_r} - tg\kappa_r \sin\lambda_s \,.$$

Accordingly, tool-in-use rake angle, γ_{ne0}, in the normal plane P_n, at selected point 0 on major edge is:

$$\gamma_{ne0} = \gamma_{n0} + \psi_n \,.$$

The angle η is defined in the tool-in-use coordinate system as the feed speed over tangential cutting speed:

$$tg\eta = \frac{v_s}{v} = \frac{P}{\pi d_0} \,.$$

Relation between angles of tool-in-hand geometry is:

$$tg\lambda_{s0} = tg\gamma_{p0}\sin\kappa_{r0} \,,$$

and angle γ_{p0} as a function of γ_p:

$$\gamma_{p0} = \arcsin(\frac{D}{d_0}\sin\gamma_p) \,,$$

where D, d_0 represent tool diameters.

Angle of inclination *i* in tool-in-use cutting edge plane P_{se} at selected point 0 on major edge is defined as follows:

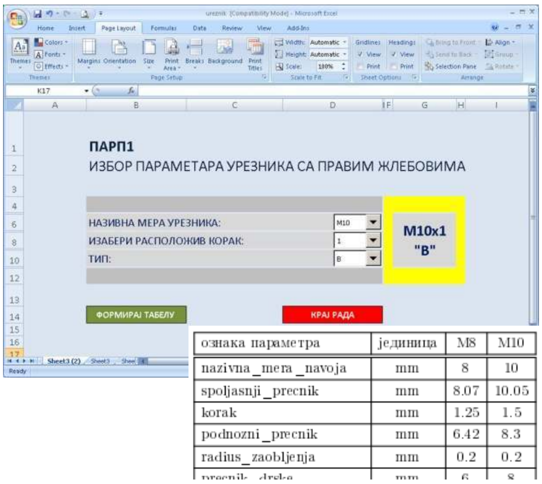
$$tg\, i = \frac{\sin\eta\cos\kappa_r\cos\lambda_s - \cos\eta\sin\lambda_s}{\sin\eta\sin\kappa_r}\sin\psi_n$$

2. MACHINE TAPS MODELING

Class of taps is modeled in the CAD programming environment of application *Autodesk Inventor 2011,* using the technique of parametric modeling. In this way, the input into the CAD software is a set of parameters that describe specific dimensions of the taps. One CAD model is created based on tap technology, and works with a number of different sets.

Parameters can be saved in `.xml` format or spreadsheet software program format. This model uses `.xls` format, *Microsoft Excel* spreadsheet format, which can be defined in a similar open-source programs (eg, *Apache OpenOffice*).

Figure 3 shows the basic screen layout of the program for the preparation of a table with the parameters based on nominal diameter, tap pitch, and tap type as inputs.



ПАРП1

ИЗБОР ПАРАМЕТАРА УРЕЗНИКА СА ПРАВИМ ЖЛЕБОВИМА

НАЗИВНА МЕРА УРЕЗНИКА: M10

ИЗАБЕРИ РАСПОЛОЖИВ КОРАК: 1

ТИП: B

M10x1 "B"

ФОРМИРАЈ ТАБЕЛУ

КРАЈ РАДА

ознака параметра	јединица	M8	M10
nazivna_mera_navoja	mm	8	10
spoljasnji_precnik	mm	8.07	10.05
korak	mm	1.25	1.5
podnozni_precnik	mm	6.42	8.3
radius_zaobljenja	mm	0.2	0.2
precnik_drske	mm	6	8

Fig. 3. Inputs of the program for the formation of a table with the parameters.

Figure 4 shows the image of cutting edges of machine tap M10 magnified 35 times, and simultaneously display image of M10 tap model obtained by the CAD software using set of parameters.

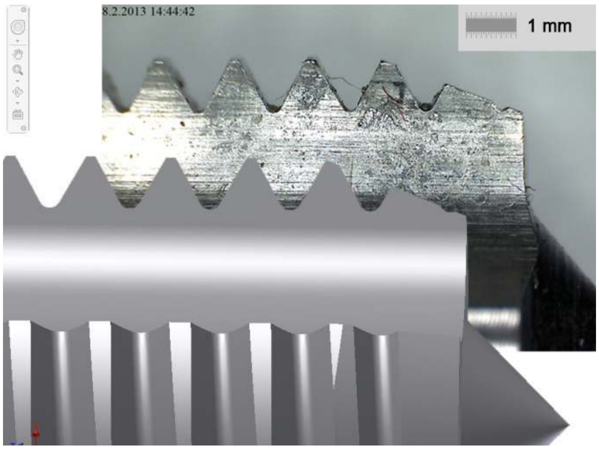


Fig. 4. The cutting edges of the tap in one flute of tap M10 (×35 magnification) and the CAD model

3. FORCE PREDICTION

Many studies [3-6] have shown that the influence of the uncut chip thickness **h** and chip width **b** on cutting force is more significant then depth of cut $\mathbf{a_p}$ and feed **f**. For example, in turning, the cross-section of cutting, with the same depth of cut and the feed has a different form, depending on the value of the tool cutting edge angle.

It is convenient to express the cutting forces in the following form [3, 4]:

$$^4F_1 = K_{tc}bh + K_{te}b,$$

$$^4F_2 = K_{rc}bh + K_{re}b,$$

$$^4F_3 = K_{fc}bh + K_{fe}b,$$

where F_1 is cutting force or main force acting in the direction of the cutting velocity, F_2 thrust force in the direction perpendicular to the produced surface and F_3 feed force in the direction of the tool travel.

The corresponding cutting constants are

$$K_{tc} = \tau_s / C_1 \cdot (\cos(\rho - \gamma_n) + tgi\ tg\nu\sin\rho),$$

$$K_{rc} = \tau_s / C_1 \cdot (\cos(\rho - \gamma_n) tgi - tg\nu\sin\rho),$$

$$K_{fc} = \tau_s / C_1 \cos i \cdot (\sin(\rho - \gamma_n))$$

where

$$C_1 = \sin\phi_n\sqrt{\cos^2(\phi_n + \rho - \gamma_n) + tg^2\nu\sin^2\rho} \,,$$

ρ represent the *average friction angle,* ν *is chip flow angle, and* K_{ie} are edge coefficients.

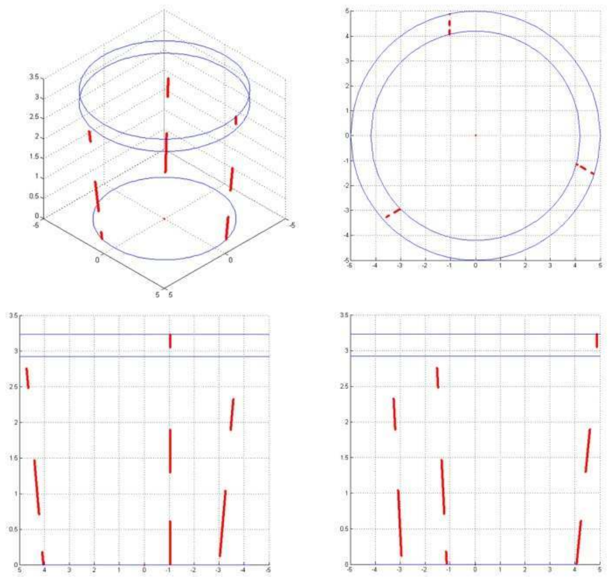


Fig. 5. Major cutting edges of tap

Oblique cutting performs major edge inclined at an angle κ_r, and two minor edges inclined at an angles α and 180º-α, where α is standard thread angle. The major cutting edges lie on the conical chamfer surface, while the minor edges lie on the flanks of the threads. Figure 5 shows major cutting edges on the conical chamfer surface obtained from CAD model of machine tap to determine the length and position of cutting edges. Now, with

$$ {}^{1}\mathrm{F} = {}^{1}_{2}R \cdot {}^{2}_{3}R \cdot {}^{3}_{4}R \cdot {}^{4}\mathrm{F}\,, $$

the cutting force and torque can be evaluated from:

$$ \mathrm{F}_z = \sum_i {}^{1}\mathrm{F}_{3i}\,, \quad \mathrm{M} = \sum_i {}^{1}\mathrm{F}_{1i} \cdot r_0 . $$

4. CONCLUSION

The force and torque acting on a cutting tool during the process are of the fundamental importance in the design of cutting tools. The prediction of cutting forces acting on the workpiece at the shear zone is essential for solving several important issues: to estimate the power of a machine tool; to estimate the straining actions that must be resisted by the machine tool components, jigs and fixtures; to evaluate the significance of various parameters of cutting forces; to evaluate the performance of new workpiece materials, tool materials, etc. with respect to machinability.

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