

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
National aerospace university “Kharkiv Aviation Institute”

**TOOL PROVISION OF AIRCRAFT ENGINES MANUFACTURE.
GEAR SHAPER CUTTERS DESIGN**

Educational aid

Kharkiv «KhAI» 2015

UDC 621.45.03.002:621.9.02 (075.8)
LBC 39.55 я 73
Т74

Розглянуто методи визначення профілю довбачів. Показано етапи проектування довбачів, наведено дані стосовно розрахунково-графічних завдань, лабораторних робіт, виконання курсових робіт, курсового та дипломного проектів.

Для студентів спеціальності «Технологія виробництва авіаційних двигунів» при вивченні курсу «Інструментальне забезпечення виробництва авіаційних двигунів», а також виконанні курсових і дипломних проектів, випускних робіт бакалаврів і магістрів.

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T74 Tool provision of aircraft engines manufacture. Gear shaper cutters design [Text]: educational aid / A. P. Petrenko, K. A. Danko, T. V. Loza, V. V. Popov. – Kharkiv: National Aerospace University “Kharkiv Aviation Institute”, 2015. – 62 p.

ISBN 978-966-662-400-3

Method of gear shaper cutters profile determination are covered in this educational aid. Stages of gear shaper cutters designing are shown. Data on computational and graphic work, laboratory works, term thesis, term and graduation projects are given.

It is designed to help the students of “Technology of aircraft engines manufacture” specialty in studying the discipline “Tool provision of aircraft engines manufacture”. The book will help to fulfill term projects, Bachelor’s & Master’s graduation projects.

Figs. 31. Tables 9. Bibliogr.: 6 titles

UDC 621.45.03.002:621.9.02 (075.8)
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ISBN 978-966-662-400-3

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Application of Gear Shaper Cutters

Gear shaper cutters are mostly used for cutting spur and helical gears, both having either external or internal teeth. In addition, gear shaper cutters, which are often referred to as pinion cutters, may be used for machining of face gears and involute worms as well as for rough relieving of hobs.

Cylindrical gears of any design can be cut with the gear shaper cutter. In particular, shaper cutters are used for machining of shoulder gears, cluster gears, etc. Machining of the cylindrical gear of small modules, having a large tooth number, a narrow face width, and a big helix angle, is especially efficient when using gear shaper cutters.

Design of Shaper Cutters

Various types and sizes of gear shaper cutters are available in the market. Commonly, two basic designs of shaper cutters are used for machining of external gears: (1) disk type and (2) deep counterbore type.

Disk-type gear shaper cutters are the most commonly used cutters for machining of external gears and splines. Figure 1 shows a typical disk-type shaper cutter. This is the common type and it is normally installed directly on the cutter spindle (Figure 2). Disk-type shapers are also used on adapters, especially when the required size is between a disk and taper shank cutter.

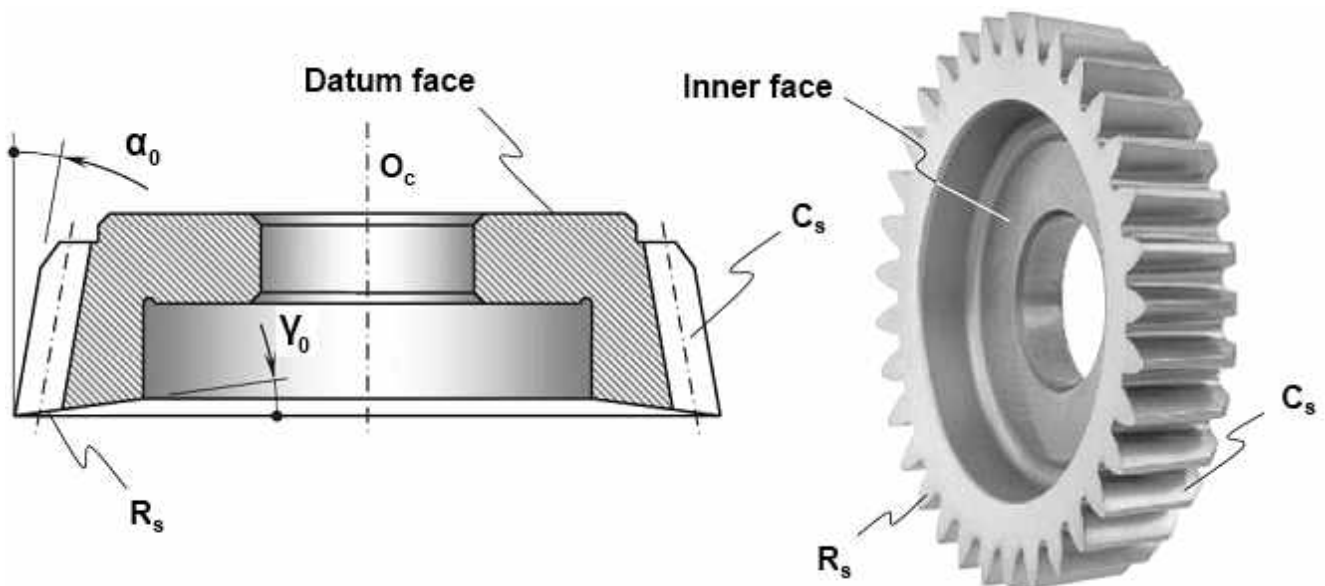


Figure 1 – A typical disk-type gear shaper cutter

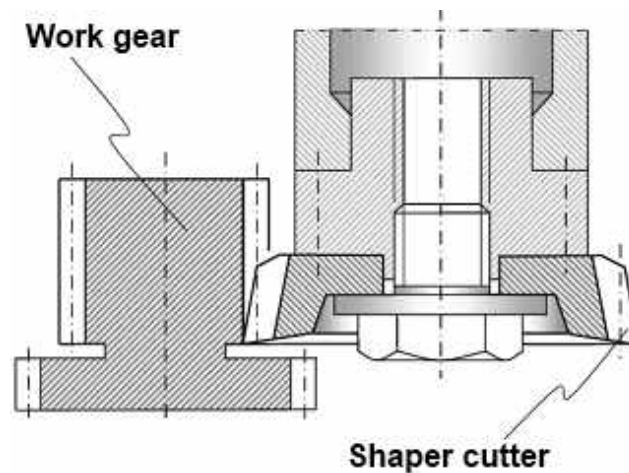


Figure 2 – Shaping of a spur gear with the disk-type gear shaper cutter

Deep counterbore-type gear shaper cutters are similar to disk-type ones, except that the blank thickness is increased to position the cutter holding nut or screw above the cutter's lifeline (Figure 3). Deep counterbore-type cutters are normally used for cutting shoulder gears and cluster gears, as well as for machining of cluster gears (Figure 4).

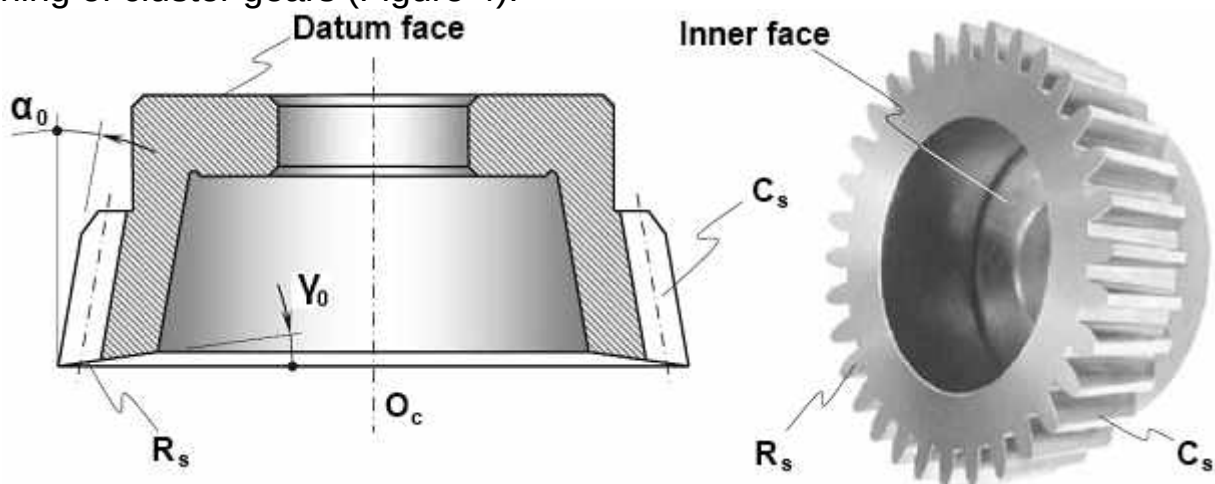


Figure 3 – A typical counterbore-type gear shaper cutter

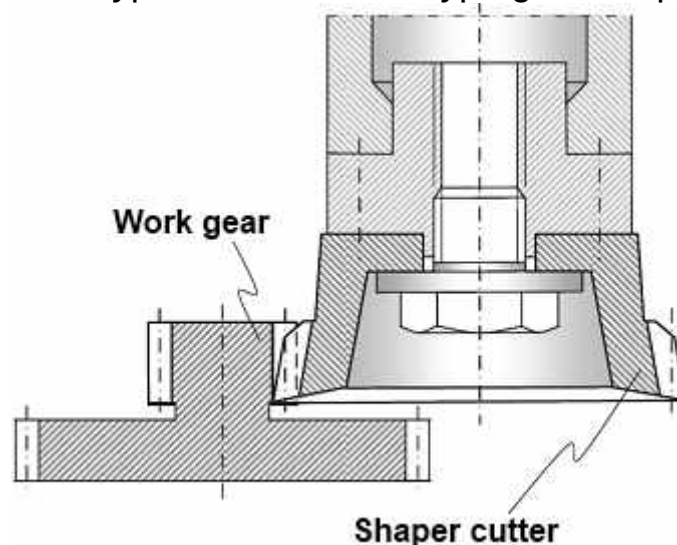


Figure 4 – Shaping of a spur gear with the counterbore-type gear shaper cutter

Shaper cutters are made of high speed steels (HSS) containing molybdenum and tungsten.

They are heat treated to a Rockwell C hardness of 64 to 65. A nitriding surface treatment further improves their wear resistance.

Titanium nitride (TiN) coating is often applied to increase permissible feeds and speeds on modern shaping machines. Shaper cutters coated with TiN increase productivity by as much as 30% without reducing tool life.

It is common to assign the rake angle at the top cutting edge of the shaper cutter equal to $\gamma_0 = 5^\circ$. Roughing shaper cutters sometimes have a rake angle as high as $\gamma_0 = 10^\circ$.

The clearance angle at the top cutting edge of the gear shaper cutter is commonly equal to $\alpha_0 = 6^\circ$. The sides of the cutter have a side clearance of about $\alpha_f = 2^\circ$.

The rake angle γ_0 and the clearance angles α_0 and α_f are all necessary to make the shaper cutter an efficient metal-cutting tool.

Commercial-quality gear shaper cutters for spur gears with $\phi = 20^\circ$ profile angle are usually available from stock. High-accuracy precision ground cutters for finishing operations and ground cutters for preshaving, pregrinding, and roughing operations are made per special order. Gear shaper cutters are made in two quality classes: class A cutters for finishing and preshaving and class B for roughing and pregrinding. Shaper cutters for finishing work are usually manufactured to a very high degree of precision.

In many high-production jobs, it is desirable to design the gear shaper cutter for a particular gear so that the cutter will do exactly what is wanted throughout its life. This is particularly true when cutters are used to preshave-cut a gear and leave an undercut. The position of the undercut must remain constant within close limits to tie in with the gear shaving cutter design.

Designing of shaper cutter begins with the determination of the generating surface of the cutting tool. For this purpose, kinematics of gear shaping operation is utilized.

Kinematics of Gear Shaping Operation

The generating surface of a gear shaper cutter is a conjugate surface to the work gear tooth surface. When machining the work gear, the generating surface T of the shaper cutter and the gear to be machined are in proper mesh with each other.

Kinematics of gear generation is the critical factor in the determination of the generating surface T of the shaper cutter. When shaping a work gear with the shaper cutter, the work gear and the shaper cutter rotate ω_g and ω_c about their axes of rotation O_g and O_c (Figure 5). The axes O_g and O_c of the rotations are parallel to each other ($O_g \parallel O_c$). The rotations ω_g and ω_c are timed with one another in compliance with the formula:

$$\frac{\omega_g}{\omega_c} = \frac{N_c}{N_g},$$

where N_g denotes the tooth number of the work gear and N_c denotes the tooth number of the shaper cutter.

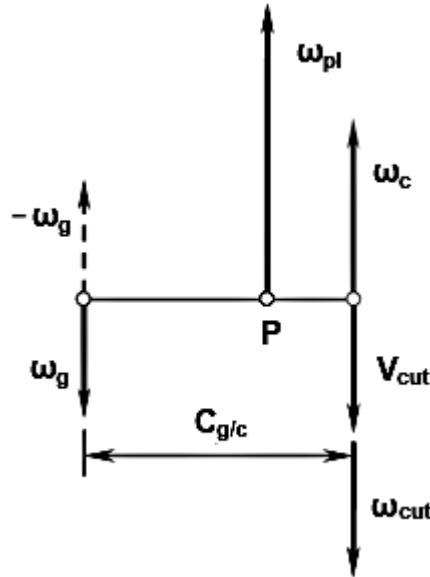


Figure 5 – Vector diagram of the kinematics of the machining process of an external gear with the shaper cutter

The shaper cutter reciprocates in its axial direction simultaneously with the rotations ω_g and ω_c . Speed of the reciprocation is designated as V_{cut} . The reciprocation of the shaper cutter is required for stock removal. In the case of a helical work gear, the rotation of the shaper cutter ω_{cut} is performed in addition to the reciprocation V_{cut} . Timing of the motions V_{cut} and ω_{cut} depends on the hand of the tooth helix of the work gear. The resultant screw motion that is composed of the motions V_{cut} and ω_{cut} is a screw cutting motion of the shaper cutter. This screw motion does not correlate to the rotations ω_g and ω_c , and is independent of the rotations ω_g and ω_c . The parameter of the screw motion is identical to the screw parameter of the work gear helix. The vector of the screw cutting motion can be pointed either in the same direction as or in the opposite direction of the vector ω_c .

The distance $C_{g/c}$ between the axes O_g and O_c of the rotations changes when the shaper cutter reciprocates back and forth (Figure 6). When the shaper cutter moves down and when it cuts the stock, the distance $C_{g/c}$ is equal to the nominal center distance in the virtual gear machining meshing, that is, it is equal to the distance between the axis of rotation of the work gear and the axis of rotation of the generating surface T of the shaper cutter.

When the shaper cutter moves back, the distance between the axes O_g and O_c is increased to a certain value. For this purpose, in most designs of gear-shaping machines the worktable with the gear reciprocates in the direction that is perpendicular to the axis of rotation O_g of the work gear. Speed of this reciprocation is designated as V_g . The reciprocation of the work gear is neces-

sary to eliminate the contact between the clearance surface of the shaper cutter teeth and the machined surface of the work gear. In this manner, the tool life of the shaper cutter is increased.

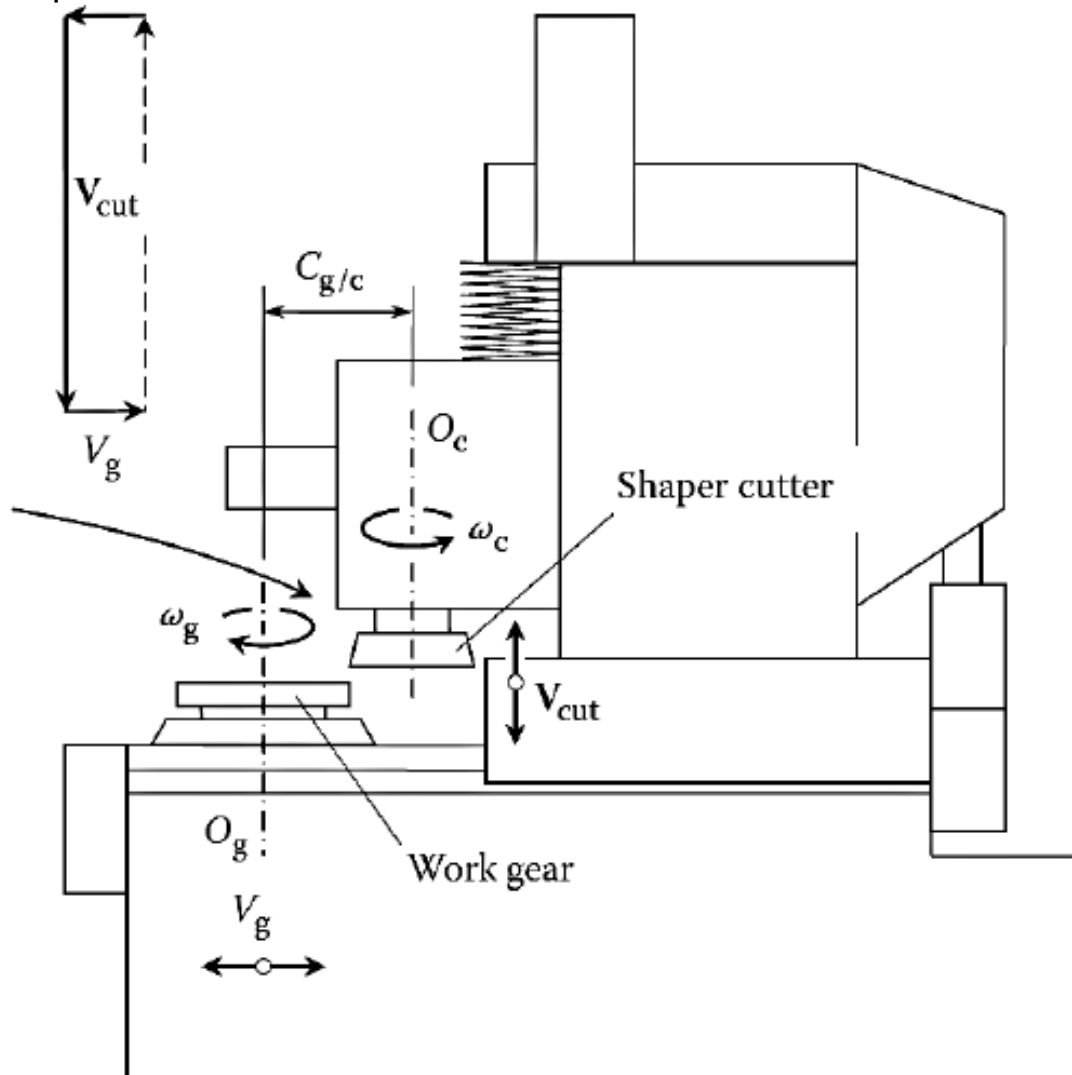


Figure 6 – Principal elements of the kinematics of gear shaping operation

Several types of in-feed motion of the shaper cutter are used in practice. The conventional method of gear shaping features either intermittent radial feed of the shaper cutter with continuous rotary feed or radial feed without rotary feed. Continuous radial and rotary feeds are available in gear-shaping machines of modern design. Numerous other types of in-feed motion of the shaper cutter are also known.

Generating Surface of a Gear Shaper Cutter

Not all of the motions of the work gear and the shaper cutter discussed above are necessarily considered when determining the generating surface of the gear shaper cutter. Only those motions that actually affect the meshing of the gear to be machined and the virtual gear represented by the generating surface of the shaper cutter are required to be considered.

Once the kinematics of the gear machining process is identified (Figure 5), an equation for the gear tooth surface to be machined is the only required input for determining the generating surface of the shaper cutter. As an example, consider the machining of a helical gear. The case of machining of a spur gear can be drawn from the above case as the simplification under the assumption that the pitch helix angle of the gear is equal to zero ($\psi_g = 0^\circ$). The set of reference systems in both cases is similar.

Consider the shaping of a helical gear using the shaper cutter (Figure 7).

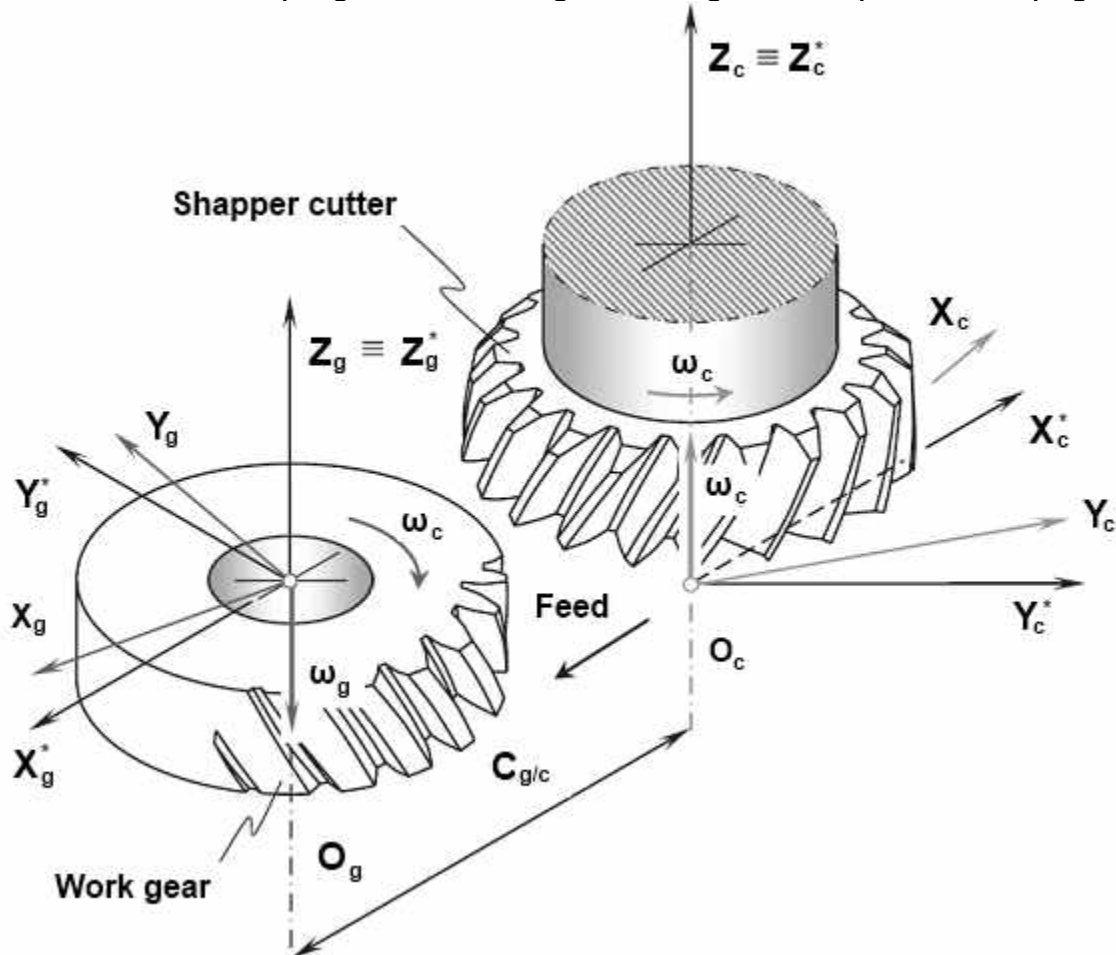


Figure 7 – The applied coordinate systems

In the Cartesian coordinate system $X_g Y_g Z_g$ associated with the gear, tooth flank surface G of the gear can be analytically described by

$$r_g(U_g, V_g) = \begin{bmatrix} r_{b,g} \cos V_g + U_g \cos \lambda_{b,g} \sin V_g \\ r_{b,g} \sin V_g - U_g \sin \lambda_{b,g} \sin V_g \\ r_{b,g} \tan \lambda_{b,g} - U_g \sin \lambda_{b,g} \\ 1 \end{bmatrix} \quad \begin{matrix} V_g^{(1)} \leq V_g \leq V_g^{(a)} \\ 0 \leq U_g \leq [U_g] \end{matrix} \quad (1)$$

where the position vector of a point r_g of the work gear tooth flank G is expressed in terms of Gaussian coordinates U_g and V_g and the design parameters $r_{b,g}$ and $\lambda_{b,g}$ of the work gear.

The kinematic method can be implemented to derive an equation for the

tooth flank surface of the generating surface T of the shaper cutter. Following this method, it is necessary to represent the work gear tooth flank G in the coordinate system $X_c Y_c Z_c$ associated with the shaper cutter. Position vector of a point $r_g^{(c)}$ of the tooth flank surface G of the work gear allows for representation in the form

$$r_g^{(c)}(U_g, V_g, \varphi_g, \varphi_c) = Rt(\varphi_c, Z_c) \cdot Tr(C_{g/c}, Y_g^*) \cdot Rt(\varphi_g, Z_g) \cdot r_g(U_g, V_g), \quad (2)$$

where

φ_g – angle through which the coordinate system $X_g Y_g Z_g$ turns relative to the stationary coordinate system $X_g^* Y_g^* Z_g^*$. Initially, before the rotation starts, axes of the coordinate system $X_g Y_g Z_g$ aligns to the corresponding axes of the coordinate system $X_g^* Y_g^* Z_g^*$;

φ_c – angle through which the coordinate system $X_c Y_c Z_c$ turns relative to the stationary coordinate system $X_c^* Y_c^* Z_c^*$. Initially, before the rotation starts, axes of the coordinate system $X_c Y_c Z_c$ aligns to the corresponding axes of the coordinate system $X_c^* Y_c^* Z_c^*$;

$C_{g/c}$ – center distance between the axis of rotation O_g of the work gear and the axis of rotation O_c the shaper cutter.

The angle φ_g may be measured between the coordinate axes X_g and X_g^* (Figure 7). Similarly, the angle φ_c may be measured between the coordinate axes X_c and X_c^* .

Of the two angles, φ_g and φ_c , one may be considered an independent parameter, whereas the other is dependent on the current value of the first one. The correlation between the angles φ_g and φ_c can be expressed by the ratio

$$\frac{\varphi_g}{\varphi_c} = \frac{N_c}{N_g}. \quad (3)$$

Ultimately, Equation (2) reduces to the form

$$r_g^{(c)} = r_g^{(c)}(U_g, V_g, \varphi_g). \quad (4)$$

Equation (4) describes the position vector of a point $r_g^{(c)}$ of the gear tooth flank surface G in its current position with respect to the shaper cutter coordinate system $X_c Y_c Z_c$. The parameter φ_g serves as the parameter of motion.

To come up with the equation for the tooth surface T , it is necessary to eliminate the parameter φ_g from Equation (4).

At a certain instant of time, not all points of the tooth flank G make contact with the tooth flank surface of the generating surface T . Only certain points of the tooth flank G make contact at which the condition of contact

$$n_g^{(c)} \cdot V_{g-c} = 0 \quad (5)$$

is satisfied.

In this equation, $r_g^{(c)}$ denotes the unit normal vector to the surface and

$\mathbf{V}_{g-c}$ is a vector of speed of the relative motion of the gear relative to the coordinate system $X_c Y_c Z_c$.

The vector $\mathbf{V}_{g-c}$ of speed of the relative motion may be represented in the form of summa of two vectors: (1) $\mathbf{V}_g$, which is the vector of linear speed of the rotation of a point of the work gear tooth flank about the axis of rotation of the work gear; and (2) $\mathbf{V}_{pl}$, which is the vector of linear speed of rotation of the gear axis of rotation $\mathbf{O}_g$ about the axis of rotation $\mathbf{O}_c$ of the coordinate system $X_c Y_c Z_c$. Ultimately, the equality $\mathbf{V}_{g-c} = \mathbf{V}_g + \mathbf{V}_{pl}$ is valid. Note that only the direction of the vector $\mathbf{V}_{g-c}$ is of importance for further consideration. Magnitude of the vector $\mathbf{V}_{g-c}$ is not important when the equation of contact is used. This is because the dot product in Equation (5) is equal to zero.

Both vectors $\mathbf{n}_g^{(c)}$ and $\mathbf{V}_{g-c}$ are functions of coordinates of a point of the moving surface $\mathbf{r}_g^{(c)}$. In other words, the dot product $\mathbf{n}_g^{(c)} \cdot \mathbf{V}_{g-c}$ allows for interpretation in the form of a function of the parameters $\mathbf{U}_g$, $\mathbf{V}_g$, and $\boldsymbol{\varphi}_g$. After solving the function with respect to the parameter of motion $\boldsymbol{\varphi}_g$, the derived expression for $\boldsymbol{\varphi}_g$ is substituted into Equation (4). This yields an equation for the tooth flank surface $\mathbf{T}$ of the generating surface of the shaper cutter. Ultimately, in the coordinate system $X_c Y_c Z_c$, the derived equation for the surface $\mathbf{T}$ can be presented in vector form

$$\mathbf{r}_c = \mathbf{r}_c(\mathbf{U}_c, \mathbf{V}_c) \quad (6)$$

In a particular case of shaping of a helical involute gear, Equation (6) casts into the expression in matrix form

$$\mathbf{r}_c(\mathbf{U}_c, \mathbf{V}_c) = \begin{bmatrix} r_{b,c} \cos V_c + U_c \cos \lambda_{b,c} \sin V_c \\ r_{b,c} \sin V_c - U_c \sin \lambda_{b,c} \sin V_c \\ r_{b,c} \tan \lambda_{b,c} - U_c \sin \lambda_{b,c} \\ 1 \end{bmatrix}, \quad (7)$$

where

$r_{b,c}$ – radius of the base cylinder of the generating surface $\mathbf{T}$ of the shaper cutter;

$\lambda_{b,c}$ – base lead angle of the generating surface $\mathbf{T}$ of the shaper cutter.

Equation (7) is very similar to Equation (1). This is a common occurrence because a screw involute surface can be properly meshed only with another screw involute surface.

Equation (7) can be expressed in terms of the design parameters of the shaper cutter.

The normal profile angle $\boldsymbol{\varphi}_{n,c}$ on the pitch cylinder of the shaper cutter is equal to the normal profile angle $\boldsymbol{\varphi}_{n,g}$ in a gear shaping operation ($\boldsymbol{\varphi}_{n,c} = \boldsymbol{\varphi}_{n,g} = \boldsymbol{\varphi}_n$). Therefore, this angle is designated as $\boldsymbol{\varphi}_n$.

Similarly, the pitch helix angle $\boldsymbol{\psi}_c$ of the shaper cutter is equal to $-\boldsymbol{\psi}_g$, where $\boldsymbol{\psi}_g$ is the pitch helix angle of the work gear.

The above-mentioned correlation between the normal profile angles of

the shaper cutter and the work gear, as well as between the pitch helix angles ψ_c and ψ_g gives the cutting tool designer the chance to alter the design parameters of the shaper cutter. The possibility of altering the design parameters can be used to improve the cutting performance of the shaper cutter. Equality of the base pitch of the shaper cutter $p_{b,c}$ to base pitch of the work gear $p_{b,g}$ is a must ($p_{b,c} \equiv p_{b,g}$).

Features of profiling of shaper cutters for machining noninvolute shapes. Shaper cutters are also used for machining of noninvolute profiles. For profiling of shaper cutters intended for machining noninvolute profiles, use of the kinematic method of profiling of generating tools is recommended.

When shaping parts having a noninvolute tooth profile, the kinematics of part surface generation (PSG) is similar to that when machining involute tooth profiles. The pitch cylinder of the radius R_{wg} of the gear to be machined is rolling without sliding over the pitch cylinder of radius R_{wc} of the shaper cutter as shown in Figure 8.

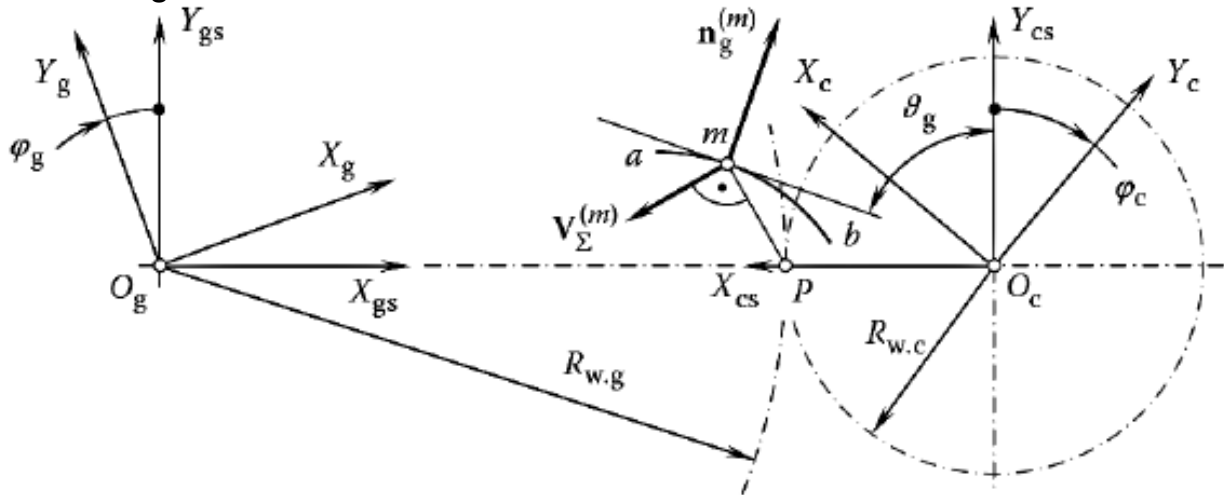


Figure 8 – Schematic of implementation of the kinematic method of profiling of generating cutting tools for profiling of the shaper cutter for machining a gear with noninvolute tooth profile

An orthogonal Cartesian coordinate system $X_gY_gZ_g$ is associated with the work gear and is rotating with it with a certain rotation ω_g . The initial position of the coordinate system $X_gY_gZ_g$ is designated as $X_{gs}Y_{gs}Z_{gs}$. Another Cartesian coordinate system $X_cY_cZ_c$ is the cutting tool reference system with which the shaper cutter will be associated after it has been designed. This reference system is rotating with the rotation ω_c . The rotations ω_g and ω_c are timed with each other so that the ratio $\omega_g R_g = \omega_c R_c$ is observed. When the work gear turns about its axis of rotation O_g through a certain angle ω_g , the shaper cutter turns about its axis of rotation O_c through the angle $\omega_c = \omega_g(R_g/R_c)$.

Shishkov's equation of contact $n_g^{(m)} \cdot V_{\Sigma}^{(m)} = 0$ is used for the purpose of profiling of the shaper cutter for the machining of the work gear having a noninvolute tooth profile. To compose the equation of contact, an analytical representation of the vector of relative motion $V_{\Sigma}^{(m)}$ of a point of interest within the

gear tooth profile is required. It is also necessary to compute a unit normal vector $n_g^{(m)}$ to the gear tooth profile at that same point of interest.

A point of interest m is chosen within the work gear tooth profile ab . In the motionless coordinate system $X_{gs}Y_{gs}Z_{gs}$, the unit normal vector $n_g^{(m)}$ to the gear tooth profile at m can be described by

$$n_g^{(m)} = -i \cdot \tan(v_g + \phi_g) + j. \quad (8)$$

Here and below, only the direction of the relative motion as well the direction of the normal vector are of importance.

In Equation (8), angle v_g designates the angle that the tangent to the tooth profile ab at the point of interest m makes with the Y_g axis of the reference system $X_gY_gZ_g$.

Vector of linear motion of the instant rotation of point m about pitch point P is designated as $V_{\Sigma}^{(m)}$. This allows for the representation of the vector $V_{\Sigma}^{(m)}$ in the form of a vector equation

$$V_{\Sigma}^{(m)} = i \cdot Y_{gc} - j \cdot X_{gc}. \quad (9)$$

Substituting Equations (8) and (9) into the equation of contact $n_g^{(m)} \cdot V_{\Sigma}^{(m)} = 0$, the particular form of the equation of contact

$$\sin(v_g + \phi_g) = \frac{X_g \cos v_g + Y_g \sin v_g}{R_{wg}} \quad (10)$$

can be derived.

Equation (10) yields computation of the angle ϕ_g at which a given point of the gear tooth profile makes contact with the corresponding point of the shaper cutter tooth profile point. Furthermore, coordinates of the point of the shaper cutter tooth profile are computed using operators of linear transformations.

Cutting Edges of the Shaper Cutter

When designing a shaper cutter the cutting edges (CE) are commonly viewed as the lines of intersection of the generating surface T by the rake surface R_s of the shaper cutter. Furthermore, the clearance surface C_s is designed so as to pass through the cutting edge at a desired clearance angle with respect to the generating surface T .

Another way of creating the cutting edges of the shaper cutter is also possible. In compliance with this second approach, the cutting edges CE are created as lines of intersection of the generating surface T by the clearance surface C_s of the shaper cutter. After that, the rake surface R_s is designed so as to pass through the cutting edge at a desired rake angle with respect to the perpendicular to the generating surface T .

In both cases, there are three surfaces – (1) generating surface T of the shaper cutter, (2) rake surface R_s , and (3) clearance surface C_s – through the cutting edge CE of the shaper cutter. Only the rake surface R_s and the clear-

ance surface C_s exist physically. The generating surface T of the shaper cutter is a phantom surface, which does not exist physically. However, surface T imposes a restriction onto the required location of the cutting edges CE.

Rake Surface of a Shaper Cutter

It is reasonable to distinguish the difference between the geometry of the rake surfaces of (a) shaper cutters for machining of spur gears from (b) those used for machining of helical gears.

Geometry of rake surface of a spur shaper cutter. The rake surface of a spur shaper cutter is shaped in the form of one of three surfaces. In reality, the rake surface R_s is shaped in the form of (1) a plane that is perpendicular to the axis of rotation of the shaper cutter, or (2) an internal cone of revolution, or (3) in particular cases, a surface of revolution of more complex geometry.

Spur shaper cutters having a rake surface shaped in the form of plane that is perpendicular to the axis of rotation of the shaper cutter have zero rake angle ($\gamma_0 = 0^\circ$). The rake surface R_s of this geometry satisfies the equation $Z_c = 0$ (Figure 9, a).

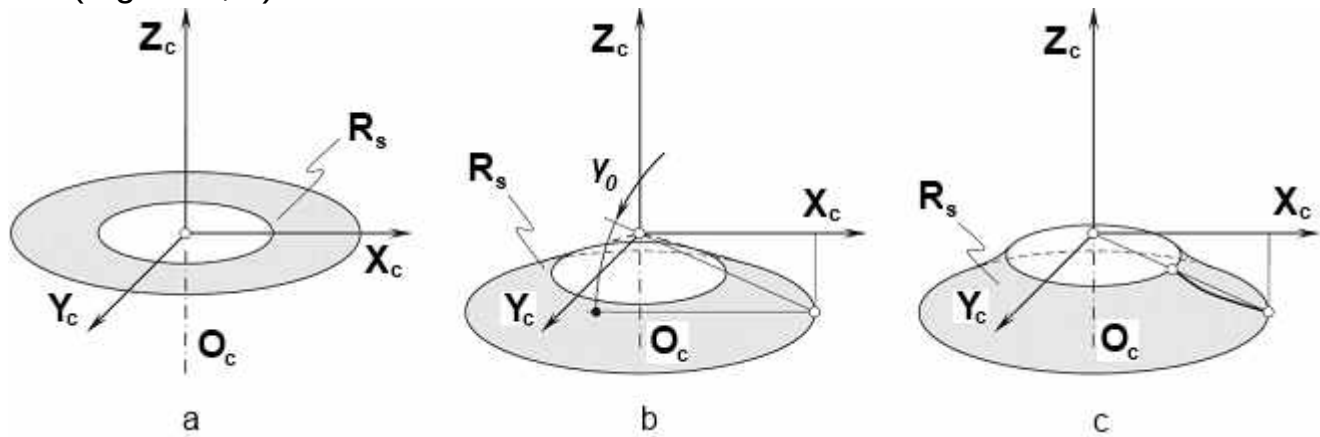


Figure 9 – Practical types of rake surfaces R_s of shaper cutters for machining spur gears

For profiling of the shaper cutter, it is preferred to use the matrix representation of the surface $Z_c = 0$:

$$r_{rs}(U_c, V_c) = \begin{bmatrix} U_c \\ V_c \\ 0 \\ 1 \end{bmatrix}, \quad (11)$$

where

r_{rs} – position vector of a point of the rake plane R_s ;
 U_c, V_c – Gaussian coordinates of the rake plane R_s .

Convenience of application is the only criterion for selecting Gaussian coordinates U_c and V_c of the rake plane R_s for a particular design of shaper cutters. For example, Gaussian coordinates U_c and V_c could be equal to the corresponding Cartesian coordinates X_c and Y_c of the rack plane R_s , that is, $U_c = X_c$ and $V_c = Y_c$.

The cutting performance of the shaper cutter can be significantly enhanced when the rake surface forms a certain desired rake angle with the perpendicular to the generating surface T of the shaper cutter. For this purpose, the conical rake surface R_s is commonly used in the design of shaper cutters (Figure 9, b). Conical rake surface can be analytically described by the matrix equation

$$r_{rs}(Z_c, V_c) = \begin{bmatrix} Z_c \tan \gamma_0 \cos V_c \\ Z_c \tan \gamma_0 \sin V_c \\ Z_c \\ 1 \end{bmatrix}. \quad (12)$$

In special cases, for precision shaper cutters implementation of a rake surface that is shaped in the form of a surface of revolution of more complex geometry is known (Figure 9, c). In this case, for the analytical description of the rake surface R_s , use of matrix equation

$$r_{rs}(U_c, V_c) = \begin{bmatrix} r_{rs}(U_c) \cos U_c \cos V_c \\ r_{rs}(U_c) \cos U_c \sin V_c \\ r_{rs}(U_c) \sin U_c \\ 1 \end{bmatrix} \quad (13)$$

has proven to be convenient. Here, the equality $r_{rs} = |r_{rs}|$ is valid.

In all three cases considered above, only one common surface (a plane, or an internal cone of revolution, or a surface of revolution) serves as the rake surface for all shaper cutter teeth. Local modifications of the rake surface within the narrow strip along the cutting edge are not considered here.

Geometry of the rake surface of a helical shaper cutter. Helical shaper cutters having a reasonably small pitch helix angle ψ_c are manufactured with a rake plane R_s similar to that shown in Figure 9, a. Helical shaper cutters of this design have one common rake plane R_s for all shaper cutter teeth.

Helical shaper cutters with a larger helix angle are designed so that each tooth has an individual rake plane R_s (Figure 10). This is mostly because the impact of the pitch helix angle onto the rake angle of the lateral cutting edges of the shaper cutter tooth cannot be neglected in this case.

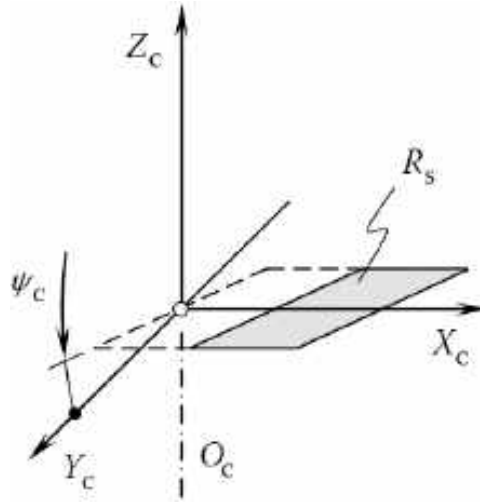


Figure 10 – Rake plane R_s of a helical shaper cutter tooth

Figure 10 gives an insight on the derivation of equation for the rake plane R_s of the helical shaper cutter

$$r_{rs}(X_c, Y_c) = \begin{bmatrix} X_c \\ Y_c \\ Y_c \tan \psi_c \\ 1 \end{bmatrix}. \quad (14)$$

The shaper cutter teeth are turned relative to each other about the axis of rotation of the cutting tool through a certain angle. The actual value of this angle θ_{cn} is equal to $\theta_{cn} = 2\pi n / N_c$. Here, n denotes the number of the tooth counting from the tooth for which Equation (14) is derived. Use of the operator of rotation $Rt(\theta_{cn}, Z_c)$ yields an expression

$$r_{rs}^{(n)}(X_c, Y_c) = Rt(\theta_{cn}, Z_c) \cdot r_{rs}(X_c, Y_c) \quad (15)$$

for the rake plane of the shaper cutter tooth that is numbered with n .

Profiling of Gear Shaper Cutters

Gear shaper cutters are round cutting tools. The reference diameter of a shaper cutter becomes progressively smaller after each resharpening of the worn tool. Because of the change in pitch diameter, the shape of the cutting edges of a new shaper cutter and its shape after resharpening are not identical. This factor must be taken into account when designing a gear shaper cutter.

The following discussion is largely based on the analysis of meshing of a partially ground gear shaper cutter with the auxiliary phantom rack Rt .

In the case under consideration, the generating surface T of the gear shaper cutter is formed as the enveloping surface to successive positions of a phantom rack surface. The phantom rack surface Rt serves as the auxiliary generating surface of the shaper cutter. The rack surface Rt properly meshes with the gear to be machined as well as the generating surface T of the shaper cutter. Application of the second approach of forming of the generating surface T of the gear shaper cutter is convenient from the standpoint of the reduction of diameters after every resharpening of the shaper cutter.

Consider an example of meshing of the auxiliary rack surface ***Rt*** with the generating surface ***T*** of the gear shaper cutter (Figure 11).

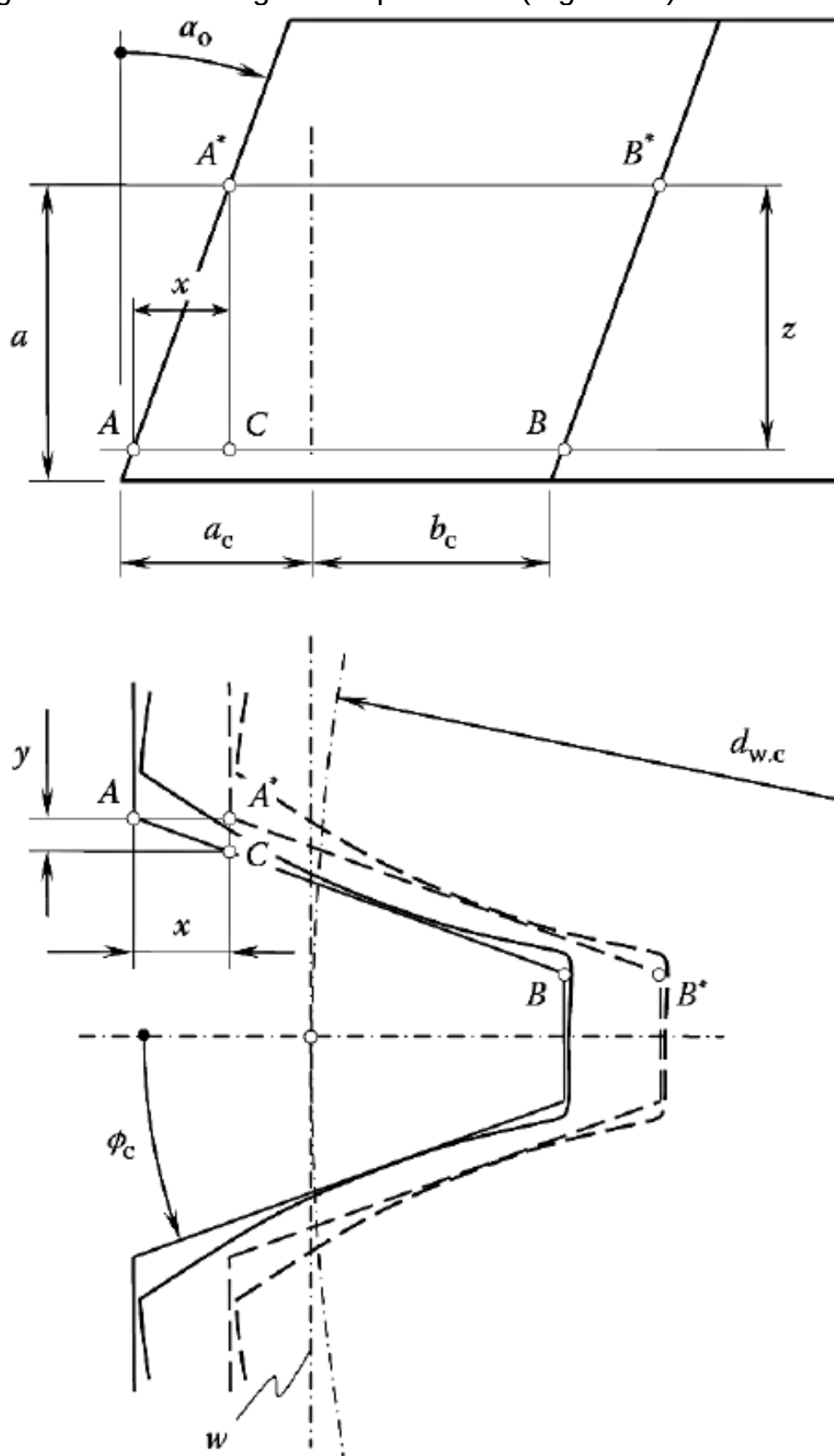


Figure 11 – Schematic of meshing of the auxiliary rack surface ***Rt*** with the generating surface ***T*** of the gear shaper cutter

The example is used to illustrate how different portions of the generating surface T have to change their relative orientation when the reference diameter of the shaper cutter becomes increasingly smaller after every reshaping of the gear cutting tool. The geometry of the portions of the generating surface remains the same as it is for the new gear shaper cutter. It has been proven convenient to use the auxiliary rack surface Rt for illustrative purposes.

Consider the cross-sectional view of the rack by a plane that is perpendicular to the axis of rotation O_c of the gear shaper cutter. When the surface T is generating, the pitch line w of the auxiliary rack rolls without sliding over the pitch circle of the diameter $d_{w.c}$. The involute tooth profile of the generating surface T is shaped in the form of the enveloping surface to successive positions of the auxiliary rack Rt when the pitch line w rolls over the pitch circle.

To be capable of cutting the stock, a positive clearance angle is necessary at all cutting edges of the tooth of the gear shaper cutter. The practical way to create the required clearance angles at all cutting edges of the shaper cutter tooth is to design the shaper cutter in such a way that the clearance angle α_0 at the top cutting edge corresponds to the clearance angles at the lateral cutting edges. To do this, the configuration of portions of the generating surface T through the lateral sides of the tooth profile should have to be changed as the outer diameter of the gear shaper cutter keeps getting smaller. In this way, the clearance angles of a certain value can be obtained on the lateral cutting edges of the shaper cutter.

Let us assume that the nominal cross section of the generating surface T aligns with the cross section by the plane through points A and B . The plane of the nominal cross section is perpendicular to the axis of rotation O_c . The ordinary involute tooth profile of the generating surface T is formed in the nominal cross section. Calculations of most of the design parameters of the gear shaper cutter are usually performed for the nominal cross section.

In the nominal cross section, the tooth profile of the gear shaper cutter can be specified in terms of the following design parameters: addendum $a_c = 1.25 m$ [mm] (here and below, the shaper cutter module is denoted by m), dedendum $b_c = 1.25 m$ [mm], reference diameter $d_{w.c} = m N_c$ (where the shaper cutter tooth number is denoted by N_c), nominal circular tooth thickness $t_n = \pi m / 2$ [mm]; the circular space width is equal to the circular tooth thickness.

The actual value of the circular tooth thickness exceeds its nominal value:

$$t = t_n + 0.5 B, \text{ mm}, \quad (16)$$

where B designates backlash in the gear transmission that comprises two gears in mesh.

The cross section by the plane through points A^* and B^* is an arbitrary normal cross section of the generating surface T (see figure 11). The arbitrary normal cross section is at a certain distance z from the nominal normal cross section. Within the arbitrary normal cross section, the tooth profile of the generating surface T of the gear shaper cutter can be generated by the auxiliary rack that is identical to the auxiliary rack Rt . However, in this cross section, the

auxiliary rack **Rt** is closer to the axis of rotation O_c of the shaper cutter. The distance x at which the auxiliary rack **Rt** within the arbitrary normal cross section is shifted toward the axis O_c relative to its initial position can be computed from the formula

$$x = z \tan \alpha_0, \quad (17)$$

where α_0 is the desired clearance angle at the top cutting edge of the gear shaper cutter tooth.

After it has been shifted, the auxiliary rack **Rt** generates the corresponding tooth profile of the generating surface **T**. The profile shift correction coefficient ξ_c in this case is

$$\xi_c = \frac{x}{m} = \frac{z \cdot \tan \alpha_0}{m}. \quad (18)$$

It is critically important to point out that the coefficient of correction ξ_c is a function of the z coordinate $[\xi_c = \xi_c(z)]$.

The parameters of rolling motion of the auxiliary rack **Rt** remain the same for both initial normal cross section and any arbitrary normal cross section. Therefore, the reference diameter $d_{w.c}$ of the gear shaper cutter when it is meshing with the auxiliary rack **Rt** also retains its original value. The pitch circle of the diameter $d_{w.c}$ is the circle at which the circular pitch P_c of the shaper cutter teeth is equal to the pitch of the auxiliary rack **Rt** teeth ($P_c = \pi m$).

The base diameter $d_{b.c}$ of the gear shaper cutter can be computed from the formula

$$d_{b.c} = d_{w.c} \cos \varphi_c, \quad (19)$$

where φ_c is the profile angle of the auxiliary rack **Rt**.

As follows from Equation (19), the base diameter at any arbitrary normal cross section has the same value as that in the nominal normal cross section.

The rest of the design parameters of the gear shaper cutter tooth in the arbitrary normal cross section can be expressed in terms of the corresponding design parameters measured in the nominal normal cross section of the shaper cutter. For example, the shaper cutter tooth addendum a_c^* is equal to

$$a_c^* = a_c + z \cdot \tan \alpha_0 = 1.25 m + z \cdot \tan \alpha_0, \text{mm}. \quad (20)$$

To compute for the gear shaper cutter tooth dedendum b_c^* , the formula

$$b_c^* = b_c - z \cdot \tan \alpha_0 = 1.25 m - z \cdot \tan \alpha_0, \text{mm}, \quad (21)$$

can be used.

Whole depth $h_{t.c}$ remains the same

$$h_{t.c} = a_c + b_c = a_c^* + b_c^* = 2.25 m, \text{mm}. \quad (22)$$

Tooth thickness of the gear shaper cutter requires special treatment. In an arbitrary normal cross section, tooth thickness t^* can be expressed in terms of the design parameters of the gear cutting tool. For this purpose, the expression

$$t^* = \frac{\pi m}{2} + B + 2z \tan \alpha_o \quad (23)$$

is derived.

The involute tooth profile within an arbitrary normal cross section of the generating surface T of the gear shaper cutter is constructed from the same base circle of diameter $d_{b,c}$ as the involute profile within the nominal normal cross section. This means that the same involute curve is used for the tooth profile both in the nominal as well as in the arbitrary normal cross section. However, the two tooth profiles differ from each other. This is because different segments of the same involute curve are used in these two cases.

An angular displacement of the involute tooth profile in the arbitrary normal cross section with respect to the tooth profile within the nominal cross section is observed. To compute for the current value of the angular displacement ε of the tooth profiles, the following formula

$$\varepsilon = \frac{t^* - t}{d_{w,c}} = \frac{\tan \alpha_o \tan \varphi_c}{d_{w,c}} \cdot z \quad (24)$$

can be used.

As follows from Equation (24), the angular displacement ε is a linear function of the z coordinate. Consequently, the locus of successive positions of the involute tooth profile in various locations of the arbitrary normal cross section when it moves along the axis of rotation O_c of the gear shaper cutter is within a screw surface of constant axial pitch. The axial pitch P_x of the surface is equal to

$$P_x = \frac{\pi d_{w,c}}{\tan \alpha_o \tan \varphi_c}. \quad (25)$$

Equation (25) immediately follows from Equation (24) when the angle of 2π is substituted instead of an arbitrary value of the angular displacement ε . Under such a scenario, the equality $z = P_x$ is observed.

Critical Distance to the Nominal Cross Section of the Gear Shaper Cutter

A cross section of the generating surface T of the gear shaper cutter for which the design parameters of the cutting tool are computed is commonly referred to as the nominal cross section of the shaper cutter.

Parameters of the tooth profile of the gear shaper cutter that has been re-sharpened differ, for many reasons, from that of the new shaper cutter. It is practical to design a shaper cutter so that deviations of the tooth profile of the new shaper cutter are of maximal permissible values. After every reshaping of the gear shaper cutter, the tooth profile deviations are becoming smaller. At a certain cross section, the tooth profile deviations of the gear shaper cutter are equal to zero. Further resharpenings cause progressively larger deviations of the gear shaper cutter tooth profile. The sign of the deviations is opposite to the

sign of the deviations of the new shaper cutter. Ultimately, at a certain cross section, the deviations reach values of the corresponding tolerances. The distance in the axial direction of the gear shaper cutter between the initial cross section of the generating surface T and the cross section that corresponds to the completely worn out shaper cutter is of critical importance to the cutting tool designer. It specifies the location of the nominal cross section of the gear shaper cutter.

The nominal cross section of the gear shaper cutter is at a distance a in the axial direction from the corresponding cross section of the new shaper cutter. Distance a is half a distance between the cross sections of the new and the worn-out gear shaper cutter.

It is desirable to design a shaper cutter with the greatest possible distance a . The greater the distance a , the larger the number of resharpenings of the gear shaper cutter allowed. This means that a larger number of gears can be machined during the life span of the given shaper cutter. In this way, the cost of the gear shaper cutter per machined gear can be significantly reduced.

The maximal length of distance a is limited by two major factors.

First, distance a affects the length of the top cutting edge of the gear shaper cutter. The greater the distance a , the shorter the top cutting edge becomes. If the shaper cutter is inappropriately designed, then either the length of the top cutting edge is insufficiently short or a shaper cutter tooth pointing may be occurring. The life span of a gear shaper cutter having a short top cutting edge is shorter compared to the life span of a gear properly designed shaper cutter.

Second, distance a also affects the parameters of the transient profile that connects the bottom land and the involute tooth profile of the cut gear. When distance a exceeds a certain allowed value, the transient profile can spread out beyond the allowed limits.

It has been proven in practice that the distance a for which the length of the top cutting edge is sufficient also satisfies the requirements imposed by the parameters of the transient profile. Therefore, the optimal value of distance a can be computed from the condition of sufficient length of the top cutting edge of the gear shaper cutter.

The length of the top cutting edge $t_{o.c}$ must not be shorter than a specific allowed value, $t_{o.c} \leq [t_{o.c}]$. The shortest allowed length $[t_{o.c}]$ of the top cutting edge depends on module m of the shaper cutter. It can be computed from the empirical formula

$$[t_{o.c}] = \sqrt{0,25938 m - 0,03752}. \quad (26)$$

To compute for the actual length of the top cutting edge $t_{o.c}$ of the gear shaper cutter, the following equation can be used (Figure 12)

$$t_{o.c} = 0.5d_{o.c}\nu, \quad (27)$$

where ν denotes the central angle that the top cutting edge spans over and $d_{o.c}$ is the outer diameter of the gear shaper cutter.

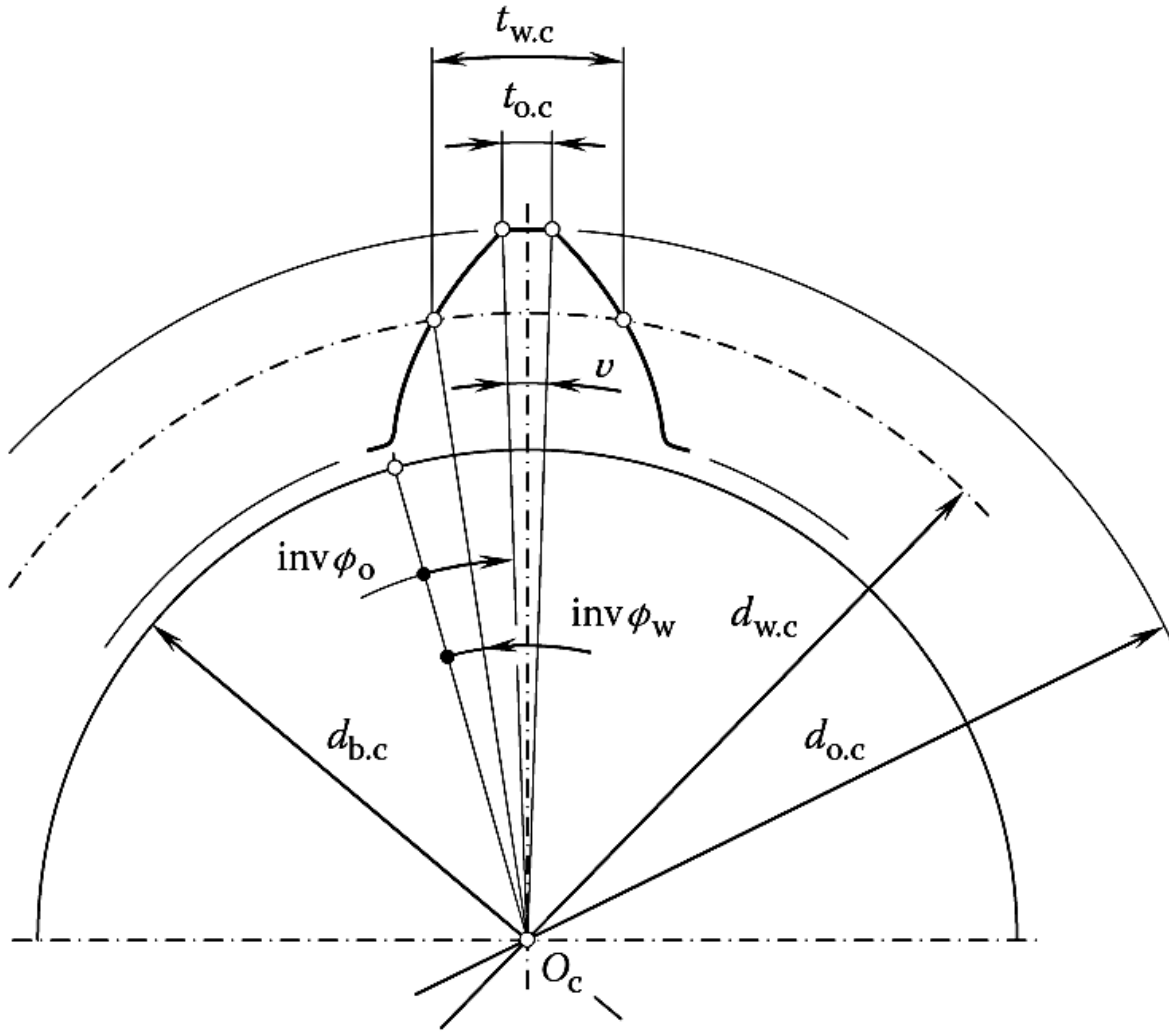


Figure 12 – Design parameters of the gear shaper cutter affecting the actual length $t_{o,c}$ of the top cutting edge

Figure 12 shows that for computation of the angle v , the following formula is valid

$$v = \frac{2t_{w,c}}{d_{w,c}} - 2(inv\phi_o - inv\phi_w), \quad (28)$$

where ϕ_o denotes the profile angle at the outer diameter $d_{o,c}$ of the generating surface T of the gear shaper cutter and ϕ_w is the profile angle at the reference diameter $d_{w,c}$ of the generating surface T .

Equation (28) can be substituted into Equation (27). This yields an expression

$$t_{o,c} = d_{o,c} \left(\frac{t_{w,c}}{d_{w,c}} - inv\phi_o - inv\phi_w \right) \quad (29)$$

for the computation of the length of the top cutting edge of the shaper cutter.

The parameters that will be entered in Equation (29) can be expressed in terms of the design parameters of the gear shaper cutter:

$$d_{o,c} = d_{w,c} + 2.5m + 2atana_o; \quad (30)$$

$$t_{w.c} = \frac{\pi m}{2} + B + 2a \tan \alpha_o \tan \varphi_w; \quad (31)$$

$$\varphi_o = \cos^{-1} \frac{d_{w.c} \cos \varphi_w}{d_{o.c}}. \quad (32)$$

To compute for the length of the top cutting edge $t_{o.c}$ of the gear shaper cutter, use of commercial software (e.g., of MathCAD) has proven to be convenient.

Another approach in determining the length of the top cutting edge $t_{o.c}$ of the gear shaper cutter is used in practice. The shortest allowed length $[t_{o.c}]$ of the top cutting edge can be computed from Equation (26). Moreover, the desired distance a can be determined by using the corresponding value of the profile shift correction coefficient ξ_c .

In the nominal cross section, addendum of standard gear shaper cutters is equal to $1.25 m$. Figure 13 illustrates the function of the reduced length of the top cutting edge $t_{o.c}/m$ of the new gear shaper cutter versus the profile shift correction coefficient ξ_c for standard gear shaper cutters having a different tooth number N_c . When computing for the coordinates of points of the curves in Figure 13, it is assumed that the backlash is equal to $B = 0.01m$.

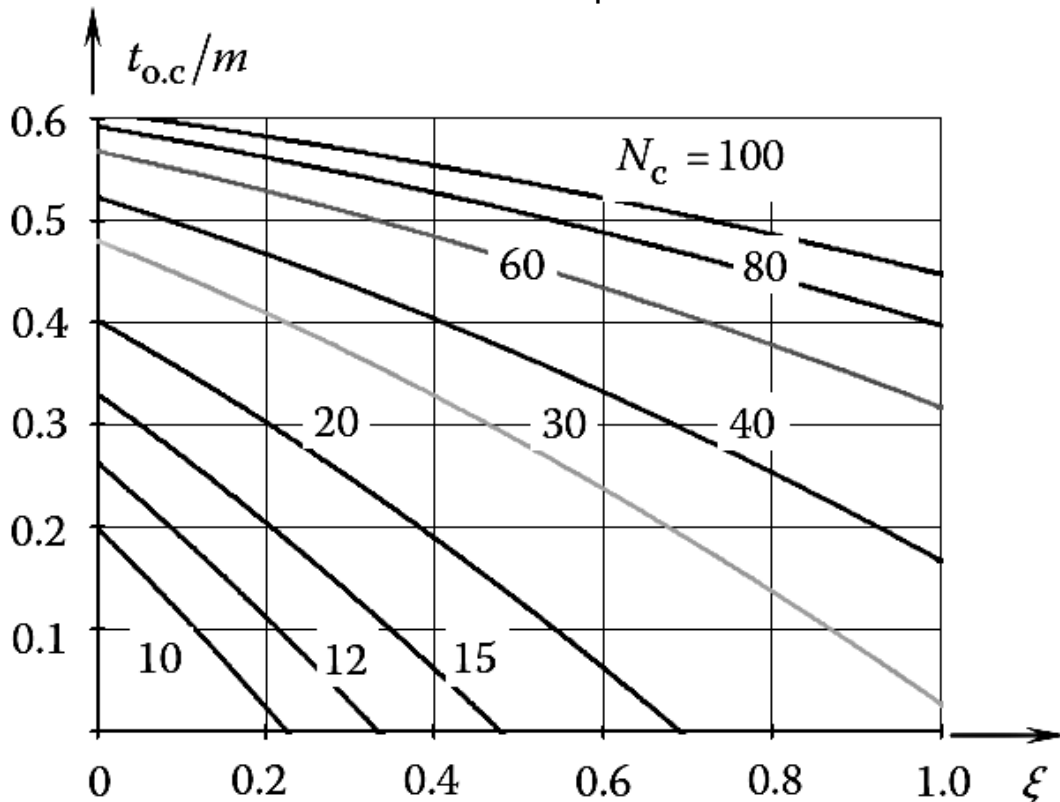


Figure 13 – Graphical interpretation of the function of the reduced length of the top cutting edge $t_{o.c}/m$ of the new gear shaper cutter versus profile shift correction coefficient ξ_c for standard gear shaper cutters having different tooth number N_c

The graph shown in Figure 13 allows for a reasonable determination of an approximate value of the profile shift correction coefficient ξ_c . Thus, the required distance a can be computed from the expression

$$a = \frac{\xi_c}{\tan \alpha_0} \cdot m. \quad (33)$$

After the desired distance a is computed, the parameters of the cross section of the generating surface T of the gear shaper cutter are as follows:

$$\text{tooth addendum} \rightarrow a_c = 1.25m + a \cdot \tan \alpha_0; \quad (34)$$

$$\text{tooth dedendum} \rightarrow b_c = 1.25m - a \cdot \tan \alpha_0. \quad (35)$$

To compute for the circular tooth thickness $t_{w,c}$, Equation (31) can be used.

Ultimately, verification of the absence of interference of the designed gear shaper cutter with the gear teeth must be performed.

Cutting Edge Geometry of a Gear Shaper Cutter Tooth

Shaper cutters for machining involute gears feature small values of the major geometrical parameters of cutting edges. Because of this, even small deviations in the geometrical parameters of cutting edges from the corresponding computed values can significantly affect the gear shaper cutter tool life and the accuracy of the machined gears. Therefore, rigorous control over the geometry of the cutting edges of gear shaper cutters tooth is advantageous.

Standard gear shaper cutters are designed so as to have the rake angle $\gamma_0 = 5^\circ$ at the top cutting edge and with the clearance angle $\alpha_0 = 6^\circ$. The inclination angle of the top cutting edge is $\lambda_0 = 0^\circ$. The values of angles γ_0 , α_0 , and λ_0 do not change within the top cutting edge. Thus, they do not require further investigation.

Special care should be given to the lateral cutting edges of the gear shaper cutter.

Angle of Inclination of the Lateral Cutting Edge

For the computation of the actual value of the angle of the inclination at the current point of interest within the cutting edge, use of elements of vector algebra is helpful.

The local Cartesian coordinate system $x_m y_m z_m$ is associated with the cutting edge of the gear shaper cutter as shown in Figure 14. Origin of the coordinate system $x_m y_m z_m$ is at the current point of interest m of the cutting edge. In reality, a Cartesian coordinate system having an arbitrary orientation of the coordinate axes can be implemented. However, for the reader's convenience, the axes are oriented as shown in Figure 14.

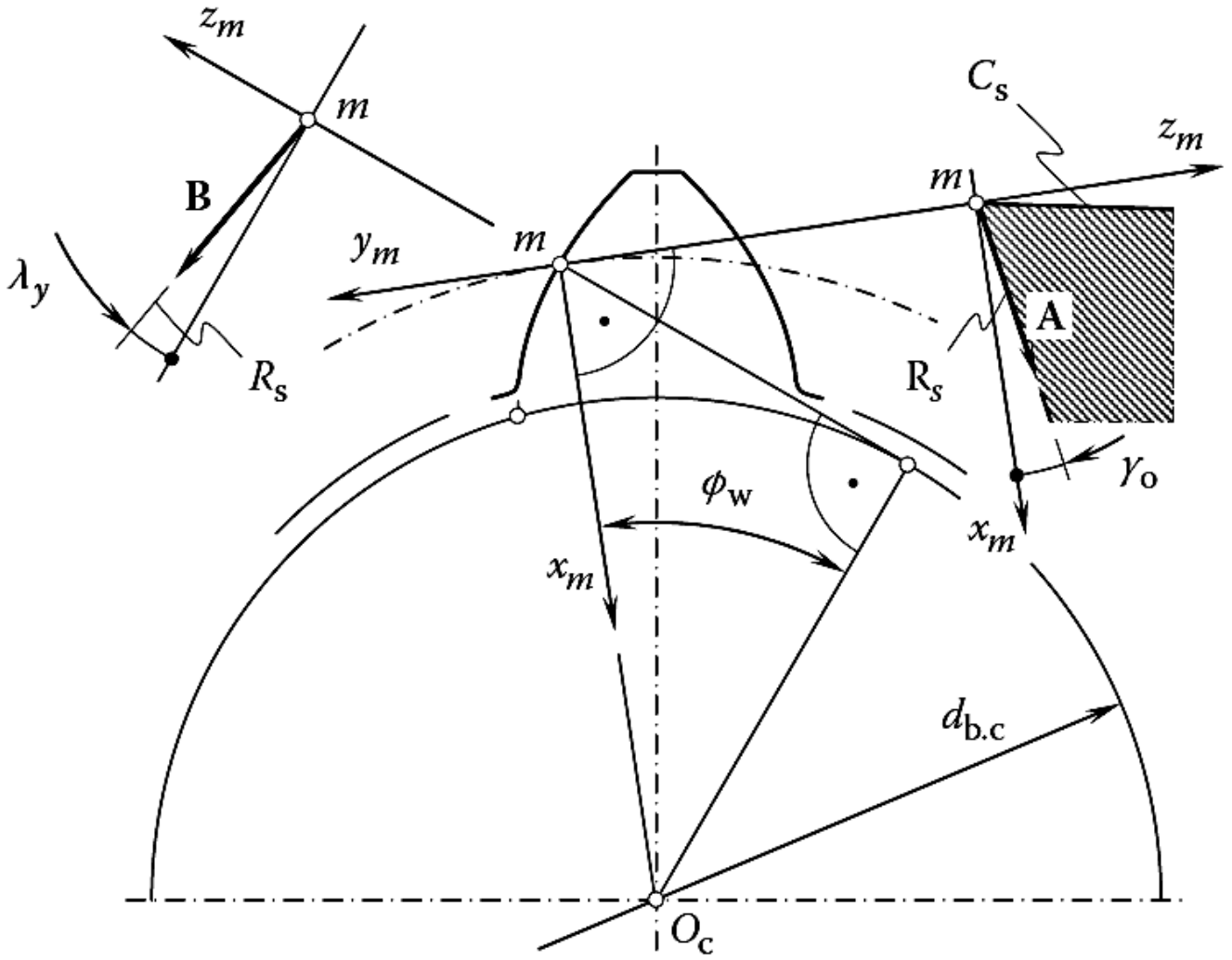


Figure 14 – Cutting edge geometry of the involute gear shaper cutter tooth: angle of inclination λ of the cutting edge

To derive the equation for the angle of inclination λ_y at point m , the following three vectors are used.

Vector **A** is the vector along the line of intersection of the rake surface R_s of the gear shaper cutter by the axial cross section through point m . The magnitude of vector **A** is chosen such that projection of vector **A** onto the coordinate plane x_my_m is equal to unit ($\text{pr}_{xy}\mathbf{A} = 1$). The following expression

$$\mathbf{A} = \mathbf{i} + \mathbf{k} \cdot \tan \gamma_o \quad (36)$$

is valid for the analytical description of vector **A**.

Vector **B** is tangent to the cutting edge of the gear shaper cutter. The magnitude of vector **B** is chosen such that the projection of vector **B** onto the coordinate plane x_my_m is equal to unit ($\text{pr}_{xy}\mathbf{B} = 1$). For the analytical representation of vector **B**, the following expression

$$\mathbf{B} = \mathbf{i} \cdot \cos \phi_{y,c} - \mathbf{j} \cdot \sin \phi_{y,c} + \mathbf{k} \cdot \tan \lambda_y \quad (37)$$

can be composed.

For solving the problem under consideration, the unit vector $\mathbf{j}$ is used.

By construction, vectors $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{j}$ are located within a common plane. At point $\mathbf{m}$ within the cutting edge, this plane is tangent to the rake surface R_s of the gear shaper cutter tooth. Because vectors $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{j}$ comprise a set of three coplanar vectors, their scalar triple product is identical to zero ($\mathbf{A} \times \mathbf{B} \cdot \mathbf{j} \equiv 0$). An expanded expression for the scalar triple product can be represented in the form of a determinant

$$\mathbf{A} \times \mathbf{B} \cdot \mathbf{j} \equiv \begin{vmatrix} 0 & 1 & 0 \\ 1 & 0 & \tan \gamma_o \\ \cos \phi_{y,c} & -\sin \phi_{y,c} & \tan \lambda_y \end{vmatrix} = 0. \quad (38)$$

A formula

$$\lambda_y = \tan^{-1}(\tan \gamma_o \cdot \tan \phi_{y,c}) \quad (39)$$

for the computation of the inclination angle λ_y immediately follows from Equation (38).

Analysis of Equation (39) reveals that a very limited variation in the angle of inclination within the lateral cutting edge of the gear shaper cutter is observed. This variation can be neglected when designing a gear shaper cutter.

Rake Angle of the Lateral Cutting Edge

The normal rake angle at the lateral cutting edge of the gear shaper cutter tooth is measured within a cross section of the cutting wedge by a plane that is perpendicular to the cutting edge at the point of interest.

The rake surface R_s of a standard gear shaper cutter is shaped in the form of a cone of revolution. The axis of rotation of the cone of revolution aligns with the axis of the shaper cutter.

To determine the normal rake angle γ_N , a local Cartesian coordinate system $x_m y_m z_m$ is used. Origin of the coordinate system $x_m y_m z_m$ is at the point of interest within the lateral cutting edge. Coordinate axes are oriented as shown in Figure 15.

Three vectors are used to derive the equation for the normal rake angle γ_N of the involute gear shaper cutter.

The earlier derived vector $\mathbf{B}$ [see Equation (37)] is used to derive the equation for the rake angle γ_N .

Vector $\mathbf{C}$ is along the line of intersection of the rake surface R_s by the plane that is tangent to the base cylinder of the gear shaper cutter. The magnitude of vector $\mathbf{C}$ is chosen so that the projection of vector $\mathbf{C}$ onto the coordinate plane $x_m y_m$ is equal to unit ($\mathbf{pr}_{xy} \mathbf{C} = 1$). This yields the following expression for the analytical representation of vector $\mathbf{C}$ in the local coordinate system $x_m y_m z_m$

$$\mathbf{C} = \mathbf{i} \cdot \sin \phi_{y,c} + \mathbf{j} \cdot \cos \phi_{y,c} + \mathbf{k} \cdot \tan \gamma_m, \quad (40)$$

where γ_m denotes the rake angle in the major section plane.

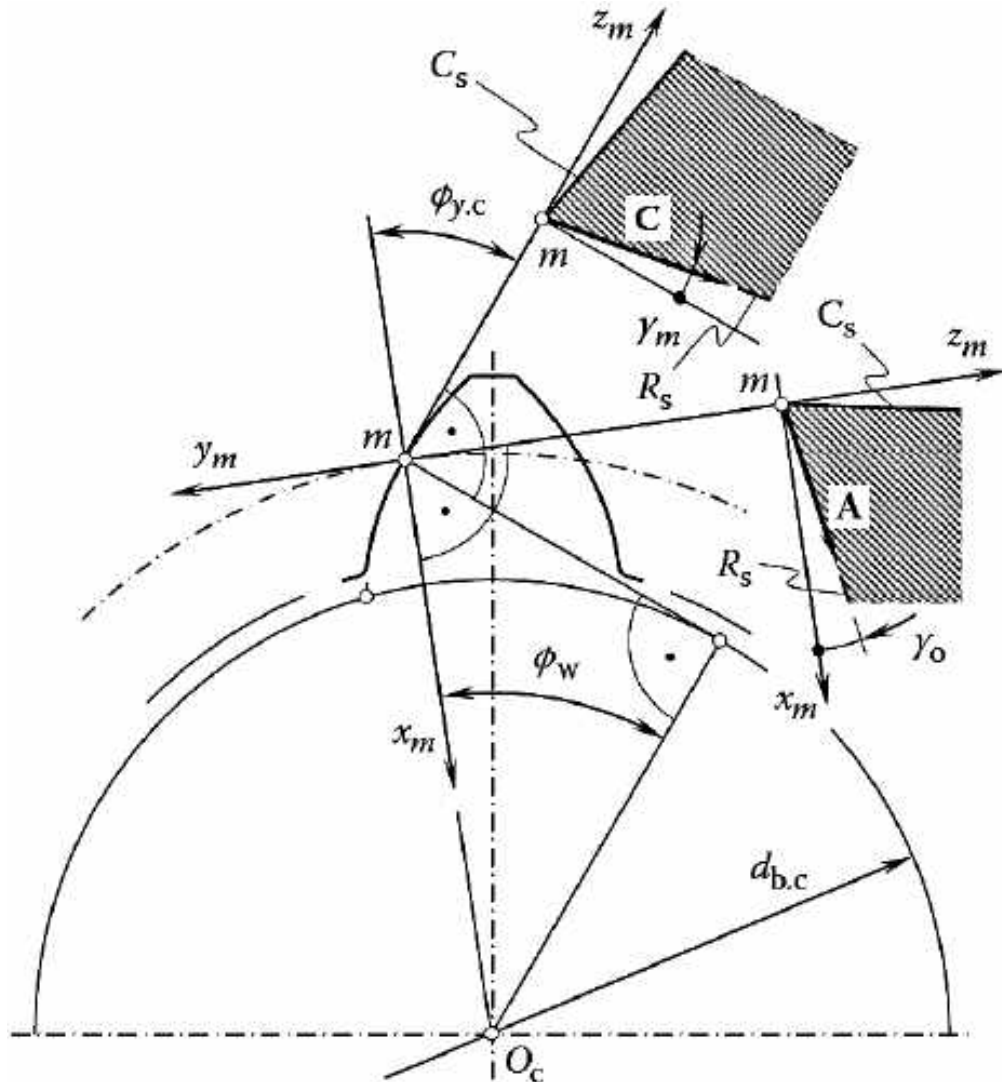


Figure 15 – Cutting edge geometry of the involute gear shaper cutter tooth: normal rake angle γ_N of the cutting edge

The third vector is the unit vector $\mathbf{j}$ along the y_m axis.

By construction, vectors $\mathbf{A}$, $\mathbf{C}$, and $\mathbf{j}$ are located within a common plane. At point $\mathbf{m}$ within the cutting edge, this plane is tangent to the rake surface R_s of the gear shaper cutter tooth. Because vectors $\mathbf{A}$, $\mathbf{C}$, and $\mathbf{j}$ comprise a set of three coplanar vectors, their scalar triple product is identical to zero ($\mathbf{A} \times \mathbf{C} \cdot \mathbf{j} \equiv 0$). The scalar triple product $\mathbf{A} \times \mathbf{C} \cdot \mathbf{j} \equiv 0$ can be expressed in the form of determinant

$$\mathbf{A} \times \mathbf{C} \cdot \mathbf{j} \equiv \begin{vmatrix} 0 & 1 & 0 \\ 1 & 0 & \tan \gamma_o \\ \sin \phi_{y,c} & \cos \phi_{y,c} & \tan \gamma_m \end{vmatrix} = 0. \quad (41)$$

Equation (41) casts into the formula

$$\gamma_m = \tan^{-1}(\tan \gamma_o \cdot \sin \phi_{y,c}) \quad (42)$$

for the computation of the rake angle γ_m at the point of interest within the lateral

cutting edge of the gear shaper cutter tooth.

The normal rake angle γ_N can be expressed in terms of (a) the rake angle γ_m and (b) the angle of inclination γ_y . For this purpose, the formula

$$\gamma_N = \tan^{-1}(\tan \gamma_m \cdot \cos \lambda_y) \quad (43)$$

can be used. This formula is known from many advanced sources (e.g., [1]).

Ultimately, after Equations (39) and (42) are substituted into Equation (43), the following formula

$$\gamma_N = \tan^{-1} \left(\frac{\tan \gamma_o \sin \varphi_{y,c}}{\sqrt{1 + \tan^2 \gamma_o \cos^2 \varphi_{y,c}}} \right) \quad (44)$$

can be obtained for the computation of the normal rake angle γ_N of the gear shaper cutter.

Clearance Angle of the Lateral Cutting Edge

A screw involute surface through the lateral cutting edge serves as the clearance surface of the shaper cutter tooth. In the cross section of the generating surface T by a cylinder that is coaxial with the gear shaper cutter, the surface T and the clearance surface C_s form the clearance angle α_f . The value of the clearance angle α_f is equal to the lead angle of the helix within the intersecting cylinder. Thus, the following formula can be used to compute for the angle α_f :

$$\alpha_f = \tan^{-1} \left(\frac{d_{y,c}}{d_{w,c}} \cdot \tan \alpha_o \tan \varphi_w \right), \quad (45)$$

where $d_{y,c}$ denotes the diameter of the intersecting cylinder through the point of interest m within the lateral cutting edge.

For the computation of the clearance angle α_f at the reference diameter of the gear shaper cutter, Equation (45) simplifies to

$$\alpha_f = \tan^{-1}(\tan \alpha_o \tan \varphi_w). \quad (46)$$

When the clearance angle α_f is known, the normal clearance angle α_N can be computed. The clearance angle α_N is measured within the cross section of the cutting wedge by a plane that is perpendicular to the cutting edge at the point of interest.

To derive the equation for the normal clearance angle α_N of the gear shaper cutter for machining involute gears, it is convenient to use the method that is based on vector algebra.

Origin of a local Cartesian coordinate system $x_m y_m z_m$ is located at the point of interest m within the lateral cutting edge of the gear shaper cutter tooth. Axes of the coordinate system $x_m y_m z_m$ are directed as shown in Figure 16.

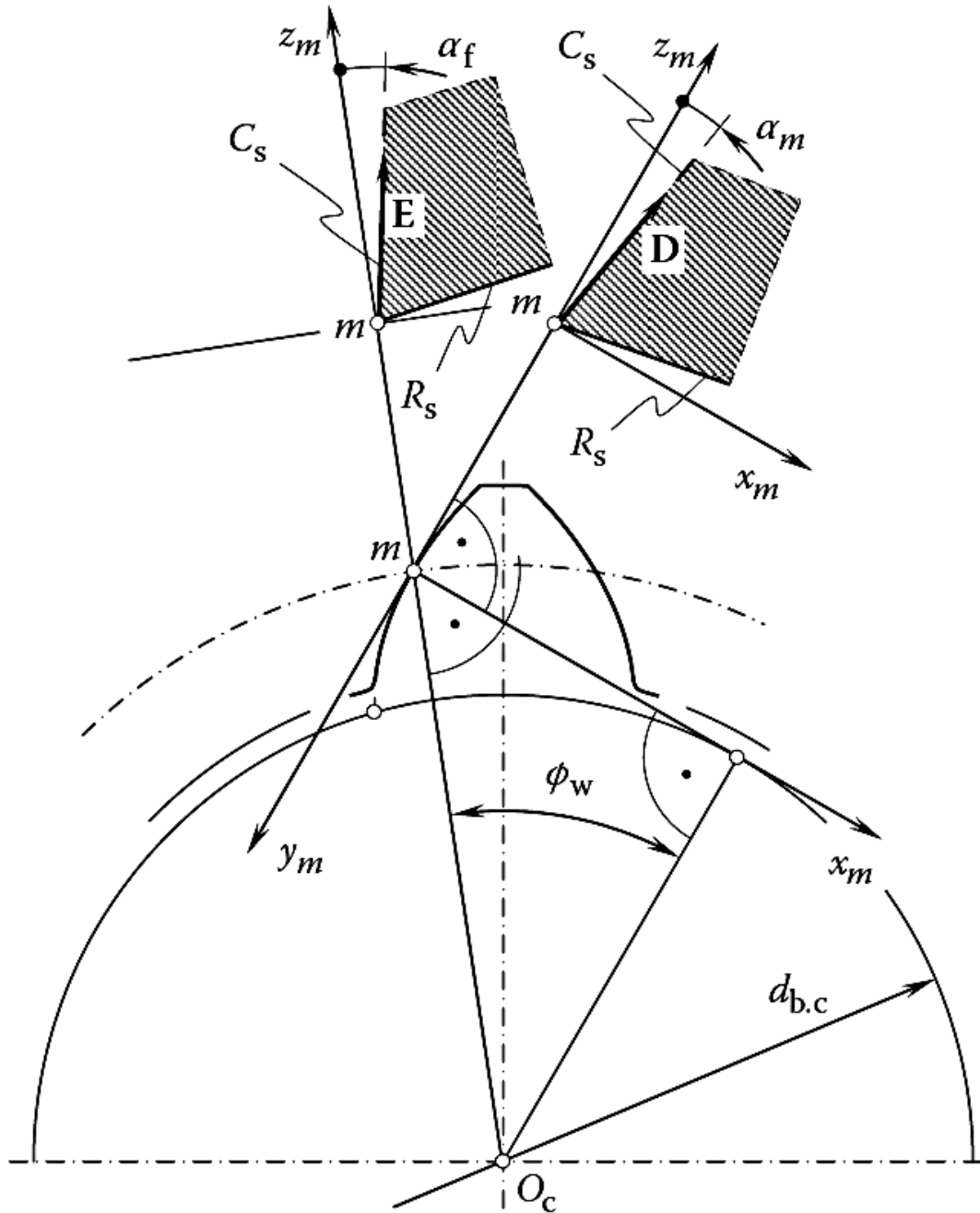


Figure 16 – Cutting edge geometry of the involute gear shaper cutter tooth: normal clearance angle α_N of the cutting edge

The vector **D** in Figure 16 is constructed so that it is tangent to the line of intersection of the clearance surface C_s by a plane that is tangent to the base cylinder of the gear shaper cutter. In the coordinate system $x_m y_m z_m$, the vector **D** can be analytically expressed as

$$\mathbf{D} = \mathbf{i} \cdot \tan \alpha_m + \mathbf{k}, \quad (47)$$

where α_m denotes the clearance angle that is measured in the major cross section of the cutting wedge.

The vector **E** through the point of interest **m** is constructed so that it is tangent to the helix within the intersecting cylinder. This allows the following expression

$$\mathbf{E} = \mathbf{i} \cdot \tan \alpha_f \cos \varphi_{y,c} - \mathbf{j} \cdot \tan \alpha_f \sin \varphi_{y,c} + \mathbf{k} \quad (48)$$

for vector $\mathbf{E}$.

Vectors $\mathbf{D}$, $\mathbf{E}$, and $\mathbf{j}$ are tangent to the clearance surface $\mathbf{C}_s$ of the gear shaper cutter tooth. They comprise a set of coplanar vectors for which the identity $\mathbf{D} \times \mathbf{E} \cdot \mathbf{j} \equiv 0$ is valid. The identity can be expressed in the form of determinant

$$\mathbf{D} \times \mathbf{E} \cdot \mathbf{j} \equiv \begin{vmatrix} 0 & 1 & 0 \\ \tan \alpha_m & 0 & 1 \\ \tan \alpha_f \cos \varphi_{y,c} & -\tan \alpha_f \sin \varphi_{y,c} & 1 \end{vmatrix} = 0. \quad (49)$$

Taking Equation (46) into account allows us to cast Equation (49) into the formula

$$\alpha_m = \tan^{-1}(\tan \alpha_o \sin \varphi_w) \quad (50)$$

for the computation of the clearance angle α_m .

An analysis of Equation (50) shows that the value of clearance angle α_m does not change within the lateral cutting edge of the gear shaper cutter tooth.

The normal clearance angle α_N can be expressed in terms of (a) the clearance angle α_m and (b) the angle of inclination λ_y . For this purpose, the formula

$$\alpha_N = \cot^{-1}(\cot \alpha_m \sin \lambda_y) \quad (51)$$

can be used. This formula is known from many advanced sources (e.g., [1]).

Ultimately, after Equations (39) and (50) are substituted into Equation (51), the following formula

$$\alpha_N = \tan^{-1}(\tan \alpha_o \sin \varphi_w \sqrt{1 + \tan^2 \gamma_o \cos^2 \varphi_w}) \quad (52)$$

can be obtained for the computation of the normal clearance angle of the gear shaper cutter.

As follows from Equation (52), the value of the normal clearance angle α_N at a point of interest within the lateral cutting edge of the gear shaper cutter depends on the rake angle γ_o .

The following values of the design parameters are common for standard shaper cutters: (a) clearance angle $\alpha_o = 6^\circ$ and (b) profile angle $\varphi_w = 20^\circ$. Under such a scenario, the normal clearance angle is $\alpha_N \approx 2^\circ 10'$.

Special Features of the Shaper Cutter Tooth Profile

Standard gear shaper cutters are designed to produce a true involute without modifications to the tooth profile. Often, gear design mandates the use of modified profiles to improve performance. Shaper cutters can be ordered with various profile modifications.

A variety of special features can be provided – and are frequently needed – in gear shaper cutter teeth. Figure 17 illustrates six different special features.

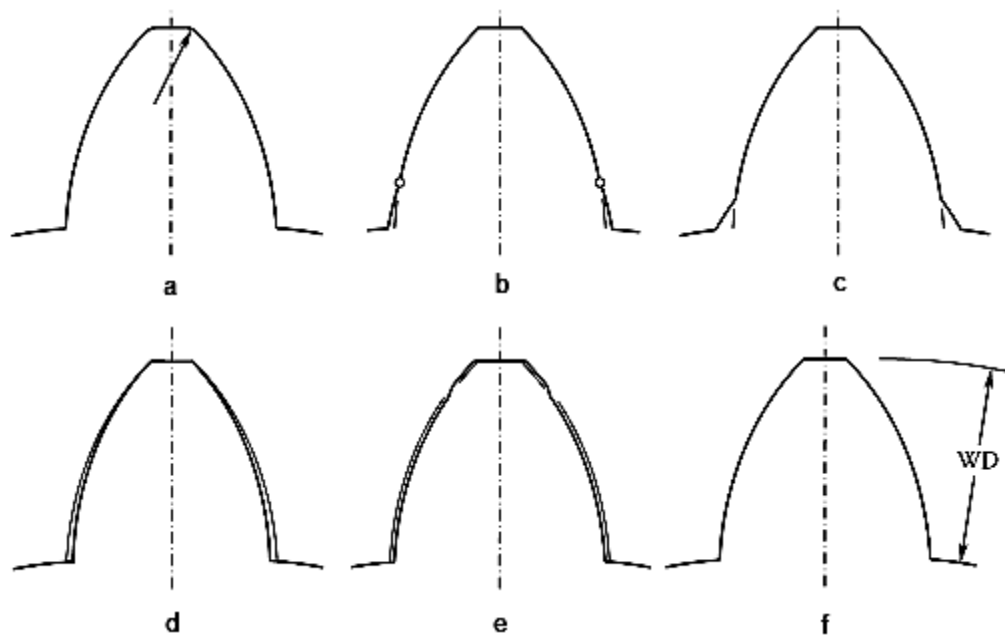


Figure 17 – Special features of the gear shaper cutter tooth profile

Root fillet. Root fillet radius modification consists of blending the corners of the tool tip with a radius that produces a controlled fillet in the root corners of the generated teeth (Figure 17, a). A root fillet increases bending strength of the gear teeth and improves fatigue life. Tool wear of the gear shaper cutter is also improved, as a sharp corner would chip off very quickly.

Tip relief. Tip relief cutters remove slightly more material near the top of the gear tooth (Figure 17, b). Tip relief compensates for interference between mating profiles and usually results in reduced gear noise. In high-speed gears, it is often desirable to minimize noise and tip bearing resulting from tooth deflection under heavy loads. For the tooth profile modification of this type, implementation of the method proposed by Radzevich [1] can be helpful.

Semitopping (or chamfer). The root area of semitopping shaper cutters is modified at an angle to create a chamfer at the tip of the generated gear teeth (Figure 17, c). Root of cutter is filled in to generate a sharp corner break of chamfer on the tips of the gear. It minimizes tip buildup during heat treatment due to nicks incurred during handling. This feature is very helpful in minimizing damage due to nicks and burrs during part handling. These nicks and burrs could result in gear noise.

Protuberance. The shaper cutter tooth profile is built up on the cutter tip to provide an undercut near the root of the gear being generated (Figure 17, d). The undercut in the gear root area acts as a clearance. The undercut is intended to facilitate subsequent finishing operations. Protuberance cutters are frequently applied for gears that are finished by shaving or grinding.

Modified pressure angle. The gear shaper cutter tooth profile is ground to a slightly lower pressure angle to provide for a constantly increasing amount of stock from root to tip of the gear generated (Figure 17, e). The tooth profile modification provides relief for subsequent finishing operations.

Full topping. The gear shaper cutter tooth is ground equal to the whole depth of the gear tooth (Figure 17, f). The outside diameter of the gear is “topped” to size when the teeth are cut. Modification of this type is used more frequently for fine pitch gearing.

In particular cases of gear machining, customized tooth profile modifications can also be used.

Shaper Cutters for Machining of Helical and Herringbone Gears

Helical gears can be cut with helical shaper cutters (Figure 18), provided that the cutter has an appropriate helix angle and the shaping machine has a helical guide of appropriate lead to twist the cutter as it strokes back and forth. Each helix angle requires its own special helical guide. A helical shaper cutter and its guide form a set of tooling required to cut a specific helical gear. Two helical cutters and two guides are required to cut a pair of meshing helical gears (left- and right-hand gears).

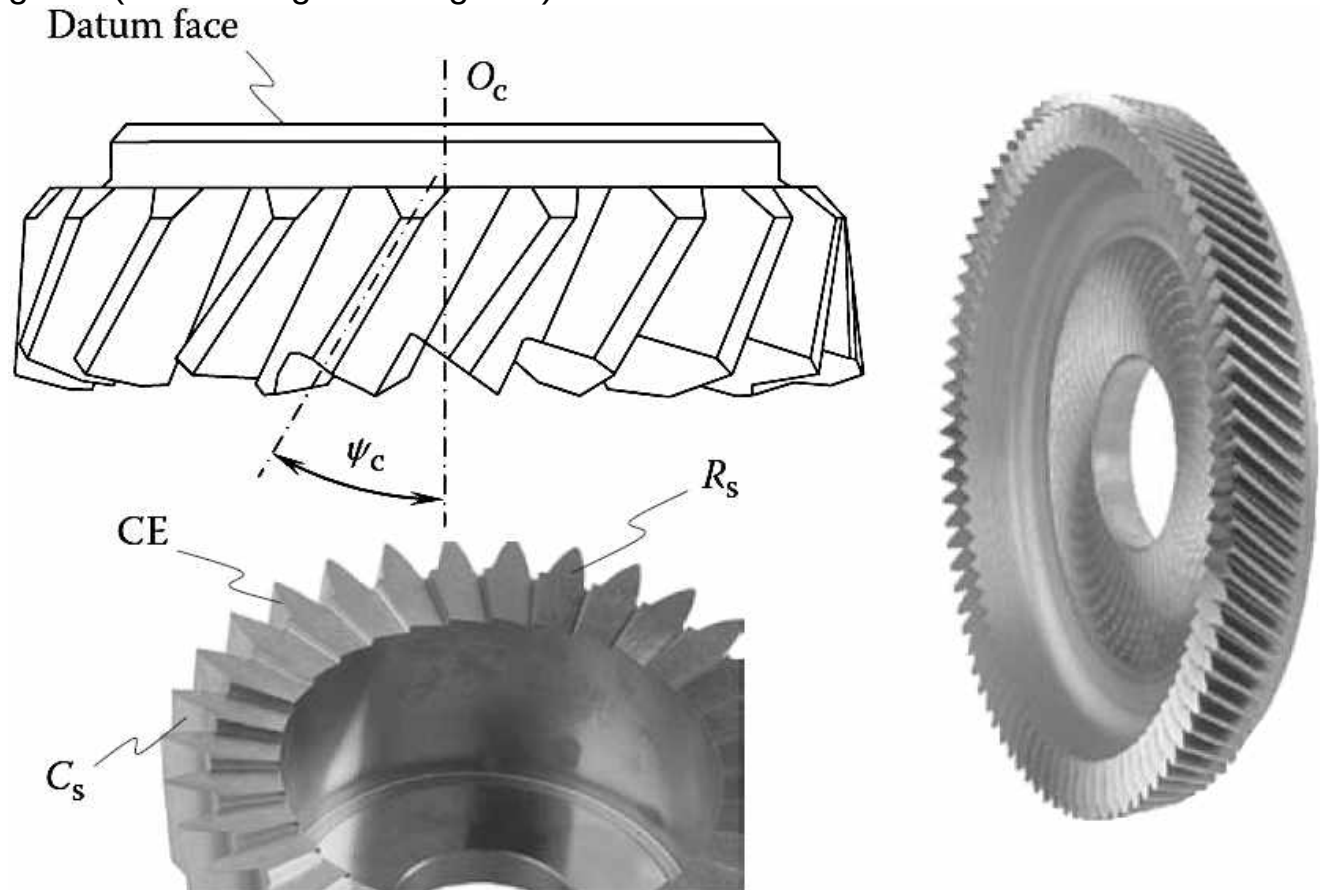


Figure 18 – Design of a helical gear shaper cutter

The helix angle that a shaper cutter produces depends on both the lead of the guide and the number of cutter teeth. The helix of the cutter must also agree with the helix angle being cut or else serious “cutter rub” will occur. The formula for the relation of cutter teeth to lead of guide is

$$\frac{\text{No. of teeth in cutter}}{\text{Lead of guide}} = \frac{\text{No. of teeth in gear}}{\text{Lead of gear}}. \quad (53)$$

Ordinarily, helical gears are cut with shaper cutters having a rake face normal to the helix of the cutter tooth. If the helix angle is low, the transverse section could serve as the rake face of the shaper tooth.

Helical shaper cutters generally require a wider recess at the bottom of the cut for full cutter runout.

Gear shaper cutters do not usually cut the same whole depth throughout their life. A shaper cutter can be designed with a front clearance angle that has such a relation to the side clearance angle that a certain number of teeth may be cut to an exact depth and thickness for the cutter. However, if this cutter is used to cut gear of substantially larger or smaller numbers of teeth, the whole depth cut will vary slightly from the design value. If a shaper cutter designed to cut an external gear is used to cut an internal gear of the same tooth thickness, the discrepancy in whole depth may be quite appreciable. In many cases, a designer of a shaper cutter does not know all the numbers of teeth that the cutter may have to cut during its life. This leads the designer to make the front clearance angle large enough so that the cutter usually cuts a little extra on the whole depth. It is usually reasoned that the problem of a little extra depth is less than the problem of having the depth too shallow.

Herringbone gears of the continuous-tooth type must be cut with a pair of gear shaper cutters working together. To make the cutting match from both sides, it is necessary to use a cutter with the top face ground normal to the cutter axis. This makes the top face angle $\gamma_0 = 0^\circ$ and it makes one side of the cutter tooth have an acute angle and the other side an obtuse angle. These features do not aid the cutting action of the tool, but they are necessary to produce the continuous tooth. A special sharpening technique has produced a good cutting edge even on the obtuse-angle side.

Gear Shaper Cutters for Internal Gear Machining Mesh

The gear shaper cutter is the primary type of gear cutting tool for machining of internal spur and helical gears. Before designing a shaper cutter for machining of a given internal gear, the generating surface of the gear cutting tool should be determined. To determine the generating surface of the shaper cutter, the internal gear machining mesh is used.

Kinematics of Shaping Operation of an Internal Gear

The internal gear machining mesh, together with a primary motion (cutting motion) of the gear cutting tool, comprises the kinematics of the shaping operation of an internal gear.

In the internal gear machining mesh, the rotation vectors of the work gear ω_g and the gear cutting tool ω_c are at a center distance $C_{g/c}$ from each other, and are parallel to each other. In this type of gear machining mesh, the vectors ω_g and ω_c are pointed in the same direction. Under such a scenario, pitch point P of the gear machining mesh is located not within the center distance $C_{g/c}$, but outside of it. The vector of instant rotation ω_{pl} is a vector through pitch point P and parallel to vectors ω_g and ω_c . An example of the configuration of rotation vectors ω_g , ω_c , and ω_{pl} is illustrated in Figure 19.

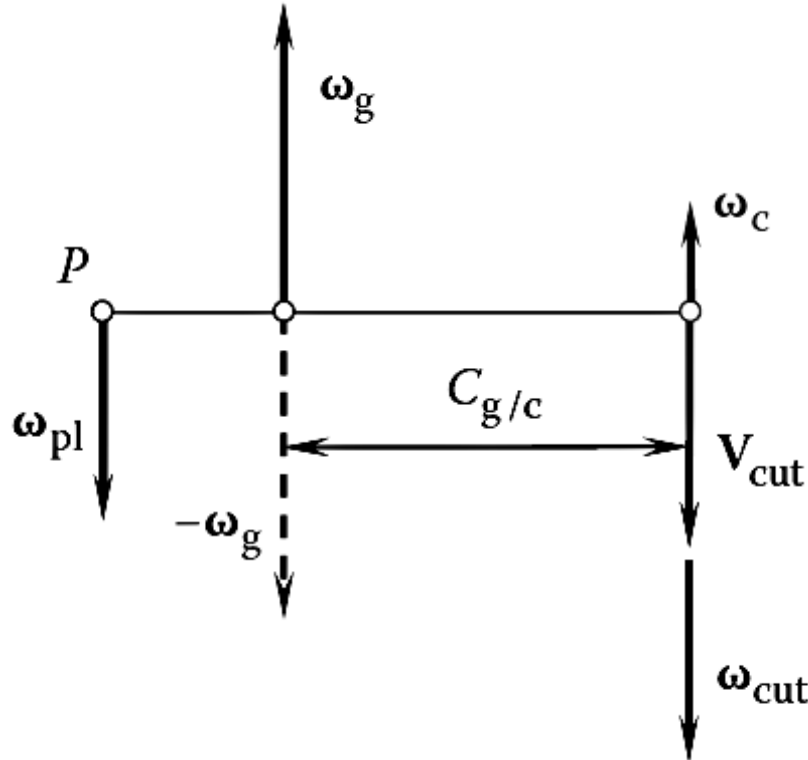


Figure 19 – Vector diagram of the kinematics of the machining process of an internal gear with the shaper cutter

Because the gear shaping operation of the pitch point takes place outside the center distance $C_{g/c}$, the rotation vectors ω_g and ω_c are not allowed to be of the same magnitude. Therefore, satisfaction of the inequality $\omega_g \neq \omega_c$ is a must for gear shaping operations of this type. Here, ω_g and ω_c denote the magnitudes of the rotation vectors ω_g and ω_c , that is, $\omega_g = |\omega_g|$ and $\omega_c = |\omega_c|$, respectively.

To satisfy the inequality $\omega_g \neq \omega_c$, either rotation ω_c must exceed rotation ω_g , or rotation ω_g must exceed rotation ω_c . In the first case, the inequality $\omega_g < \omega_c$ is valid, whereas in the second case the inequality $\omega_g > \omega_c$ is observed. The first case ($\omega_g < \omega_c$) corresponds to the operation of machining an internal gear using the shaper cutter. Shaping of an internal work gear with the shaper cutter is schematically illustrated in Figure 20.

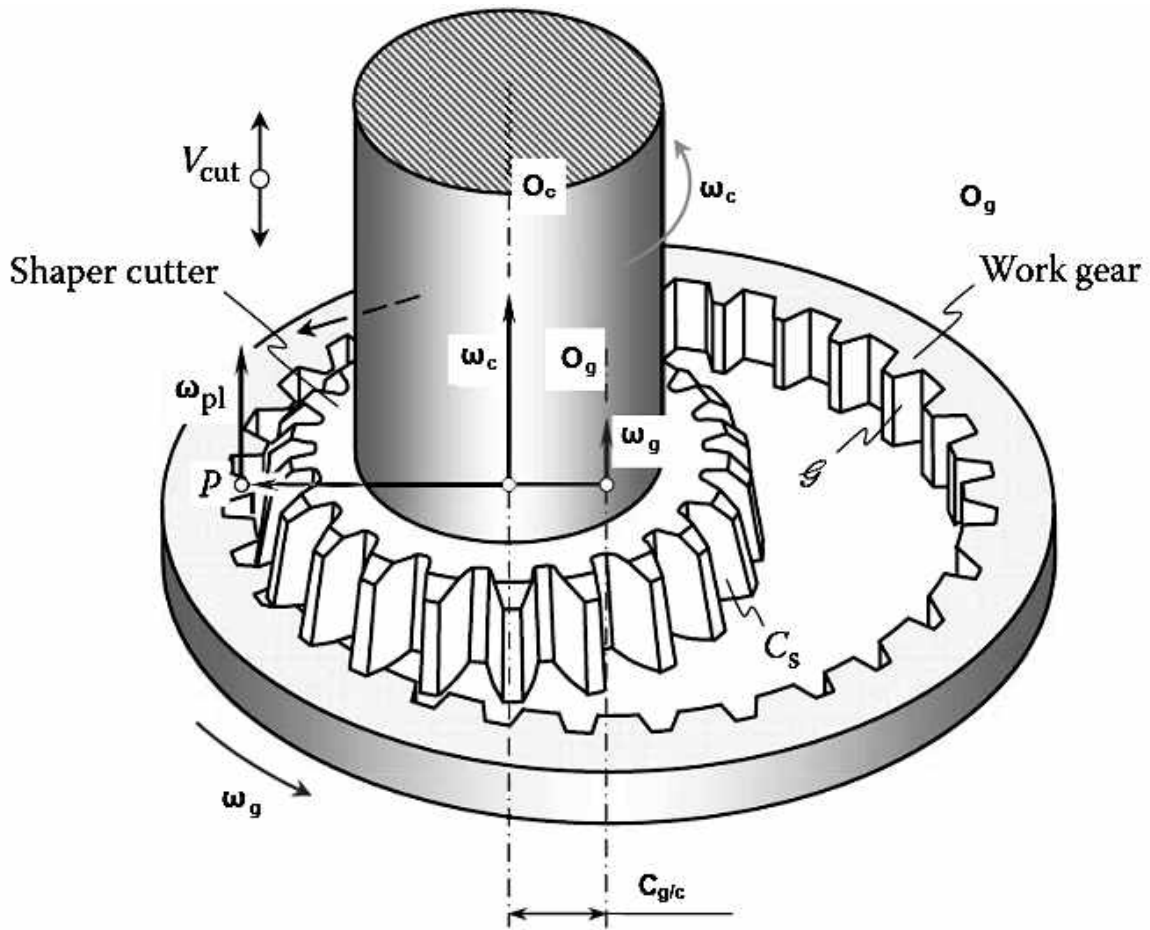


Figure 20 – Shaping of an internal work gear with the shaper cutter

The inequality $\omega_g \neq \omega_c$ is not the only constraint in the ratio between the rotations ω_g and ω_c . One more constraint is attributed to the numbers of teeth of the work gear N_g and the shaper cutter N_c , under which no interference of the gear teeth and the shaper cutter teeth is observed before teeth are engaged in the mesh and after they are disengaged from the mesh. This issue needs to be discussed as a separate topic.

The generating surface of a gear shaper cutter is conjugate to the work gear tooth surface. When shaping the work gear, the generating surface T of the shaper cutter and the gear to be machined are in proper tight mesh with each other.

The kinematics of gear generation is of critical importance for the determination of the generating surface T of the shaper cutter. When shaping an internal gear with a shaper cutter, the work gear and the shaper cutter rotate ω_g and ω_c about their axes of rotation O_g and O_c (see Figure 19). The axes O_g and O_c of the rotations are parallel to each other ($O_g \parallel O_c$).

The rotations ω_g and ω_c are timed with each other in such a way that the ratio (54) is valid:

$$\frac{\omega_g}{\omega_c} = \frac{N_c}{N_g}. \quad (54)$$

The shaper cutter is reciprocating in its axial direction simultaneously with the rotations ω_g and ω_c . Speed of reciprocation is designated as V_{cut} . Reciprocation of the shaper cutter is necessary for stock removal.

When shaping a helical work gear, the rotation of the shaper cutter ω_{cut} is performed in addition to the reciprocation V_{cut} . Timing of the motions V_{cut} and ω_{cut} depends on the hand of the tooth helix of the work gear. The resultant screw motion that is composed by the translation V_{cut} and the rotation ω_{cut} is a screw cutting motion of the shaper cutter along and about its axis. This screw motion does not correlate to rotations ω_g and ω_c , and is independent of rotations ω_g and ω_c . The parameter of the screw motion is identical to the screw parameter of the work gear helix. The vector of the screw cutting motion can be pointed either in the same direction or in the opposite direction of the rotation vector ω_c .

The distance between the axes O_g and O_c of the rotations changes when the shaper cutter reciprocates back and forth.

Design of Shaper Cutters

A detailed discussion of the design of shaper cutters reproducing an external gear machining mesh makes it easier to form a concise analysis of the design of gear shaper cutters engaged in an internal gear machining mesh when shaping gears.

Generating Surface of Gear Shaper Cutters

Most of the internal gears machined with shaper cutters are spur gears. However, internal gears having helical teeth can also be machined with shaper cutters.

The generating surface of a shaper cutter for machining internal gears is similar to that used for machining of external gears. Therefore, without going into details of the analysis, Equation (7)

$$r_c(U_c, V_c) = \begin{bmatrix} r_{b,c} \cos V_c + U_c \cos \lambda_{b,c} \sin V_c \\ r_{b,c} \sin V_c - U_c \cos \lambda_{b,c} \sin V_c \\ r_{b,c} \tan \lambda_{b,c} - U_c \sin \lambda_{b,c} \\ 1 \end{bmatrix}, \quad (55)$$

can be used for the analytical description of the generating surface T of the shaper cutter for machining of internal gears.

Equation (55) is applicable for both helical shaper and spur shaper cutters. In the latter, it is required to make the base lead angle $\lambda_{b,c}$ of the surface T equal to 90° .

Profiling of Gear Shaper Cutters

When profiling a gear shaper cutter, it is necessary to satisfy the condition under which three surfaces are passing through a common line: (1) generating surface of the shaper cutter T , (2) rake surface R_s , and (3) clearance surface C_s . These surfaces have to pass through the common line, that is, through the cutting edge CE of the shaper cutter tooth.

There are three methods of transforming the generating body of the cutting tool (a body that is made of the cutting material and bounded by the generating surface T of the cutting tool is referred to as the generating body of the cutting tool) into a workable edge cutting tool [1]:

1. intersect the generating surface T by the rake surface R_s . Then, the clearance surface C_s is a surface at a clearance angle α through the cutting edge CE.

2. intersect the generating surface T by the clearance surface C_s . Then, the rake surface R_s is a surface at a rake angle γ through the cutting edge CE.

3. construct on the generating surface T the cutting edge having optimal the inclination angle λ . Then, the rake surface R_s , and the clearance surface C_s are surfaces through the cutting edge CE.

In the first method, considered the most practical option for this particular case, the generating surface T of the shaper cutter is intersected by the rake surface R_s . The cutting edge CE of the shaper cutter is viewed here as the line of intersection of the surfaces T and R_s .

The generating surface of the shaper cutter is defined above [see Equation (55)]. An internal cone of revolution or a plane (that is orthogonal to the shaper cutter axis of rotation) is used as the rake surface R_s of the shaper cutter tooth (see Figure 9). For helical shaper cutters, the plane that is orthogonal to the pitch helix of the shaper cutter tooth (see Figure 10) can be used as the rake surface as well. Coordinates of points of the cutting edge CE satisfy both the equation for the generating surface T of the shaper cutter and the equation for the rake surface R_s . Next, the clearance surface C_s is specifically constructed so as to pass through the cutting edge CE. For the convenience of the manufacturer of shaper cutters, the desired clearance surface is approximated with a screw involute surface.

Clearance surface C_s of the chosen geometry is not exactly passing through the cutting edge CE. Because of the approximation, deviations of the actual location of the cutting edges from their desired location are unavoidable. To minimize the deviations, certain corrections can be introduced in the shaper cutter tooth profile. Determination of the critical distance to the nominal cross section is also a critical issue when designing the shaper cutter.

For internal gears, it is frequently necessary to use small cutters when the disk-type construction cannot be used. The smallest cutters are usually made shank type. When the cutters are small in diameter for the tooth size, they are made integral with a shank. If the face width to be cut is wide, the shank has to

be rather long and sturdy.

Two basic designs of shaper cutters for machining of internal gears have been developed: the shank-type shaper cutter and the deep counterbore shaper cutter that is assembled on a special adapter.

Figure 21 shows a shank-type shaper cutter and its nomenclature. Shaper cutters of this type are generally used in cutting small reference diameter internal parts. The cutter length below the taper must be adequate to accommodate the face width of the gear to be cut plus the required overtravel at the bottom of the machine stroke and available life of the cutter.

The work-holding fixture or a recess of the gear teeth in the blank may require extra length. Taper shank-type cutters are available in four taper sizes (measured at the large end of the taper).

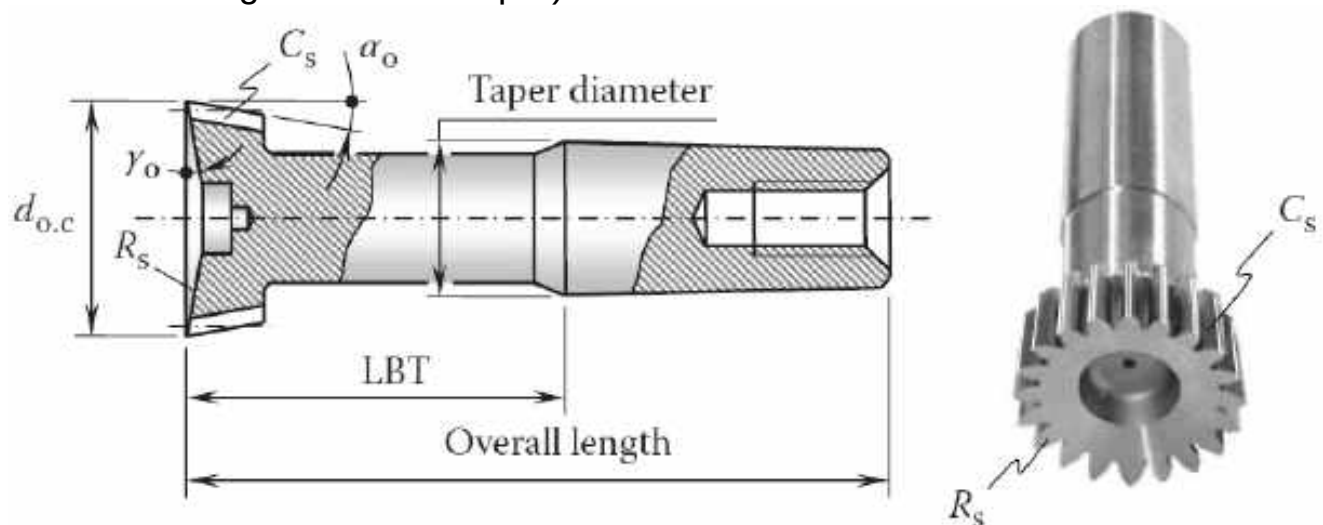


Figure 21 – Design of a shank-type shaper cutter

The reference diameter of the cutter should approximate the diameter of the taper. Flutes can be added to long cutters of small reference diameter to minimize deflection when cutting.

Taper shank cutters, which come in various sizes, normally cut small internal gears or splines. The taper fits directly into the machine spindle or indirectly with a reduction taper bushing.

The cutter has external teeth and must be small enough to avoid damaging the corners of the internal teeth.

Shaper cutters frequently have small enough numbers of teeth to cause the base circle to come high on the tooth flank. The region below the base circle may be left as a simple radial flank or it may be filled in. The filled-in design can be used to break the top corner of the gear tooth being cut. Shaper cutters can be made with a protuberance at the tip. The protuberance cuts an undercut at the root of the gear tooth. This provides a desirable relief for a shaving tool. The protuberance design is also used in some cases to permit the sides of gear teeth to be ground without having to grind the root fillet.

A small disk-type shaper cutter with a deep counterbore mounted on a special adapter is shown in Figure 22. Shaper cutters of this design are also of-

ten used for cutting of internal gear teeth.

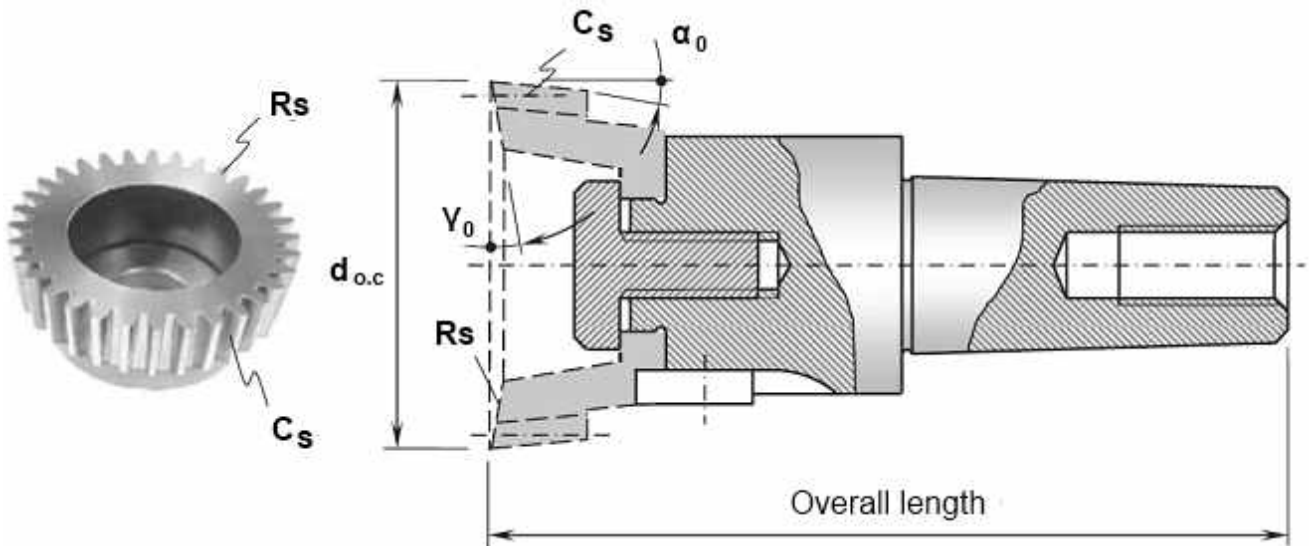


Figure 22 – Small disk-type shaper cutter with deep counterbore mounted on a special adapter

Cutting Edge Geometry of Gear Shaper Cutters

The rake angles γ_0 and γ_f at the top and lateral cutting edges, respectively, as well as the clearance angles α_0 and α_f and are all necessary to make the shaper cutter an efficient metal-cutting tool.

The geometry of three major surfaces, T , R_s , and C_s , in shaper cutters for machining gears in the internal gear machining mesh is similar to the geometry of the same major surfaces in shaper cutters for machining gears in the external gear machining mesh. Thus, for the computation of (a) angle of inclination λ , (b) rake angles γ_0 and γ_f , and (c) clearance angles α_0 and α_f , the formulae developed earlier are applicable.

It is common practice to make the rake angle at the top cutting edge of the shaper cutter equal to 5° . Occasionally, roughing shaper cutters have a rake angle as high as $\gamma_0 = 10^\circ$. The clearance angle at the top cutting edge of the shaper cutter is usually equal to $\alpha_0 = 6^\circ$. The sides of the cutter have a side clearance of about $\alpha_f = 2^\circ$.

Because of the smaller tooth number, changes in the rake angle γ_f and the clearance angle α_f within the lateral cutting edges of shank-type shaper cutters and small-diameter disktype shaper cutter with deep counterbore exceed changes in the corresponding angles γ_f and α_f for shaper cutters of conventional design.

Application of Gear Shaper Cutters

Kinematic schemes of machining of gear teeth featuring parallel rotation vectors of the same direction are used mostly for shaping of internal gears. An additional advantage of using this schematic of gear machining can be attained

when shaping an internal gear with a shoulder as depicted in Figure 23.

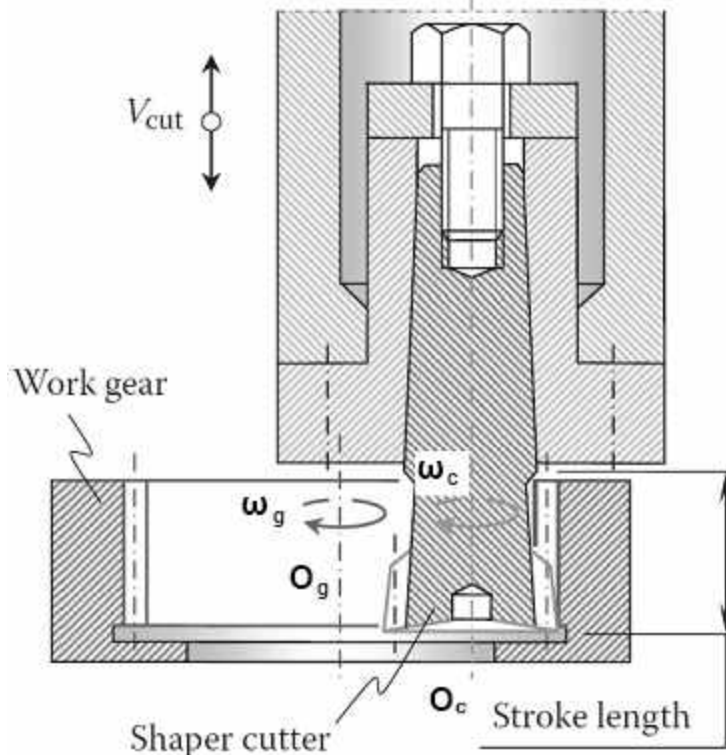


Figure 23 – Shank-type shaper cutter for machining of small-diameter internal gears with a shoulder

An internal gear and an external gear can be cut in the same cycle by mounting an internal and an external shaper cutter on the same arbor (Figure 24). Machining parameters for each cut are performed in the numerical control. Machining of the cluster gear in a single setup is economical because it saves time in remounting of the shaper cutters.

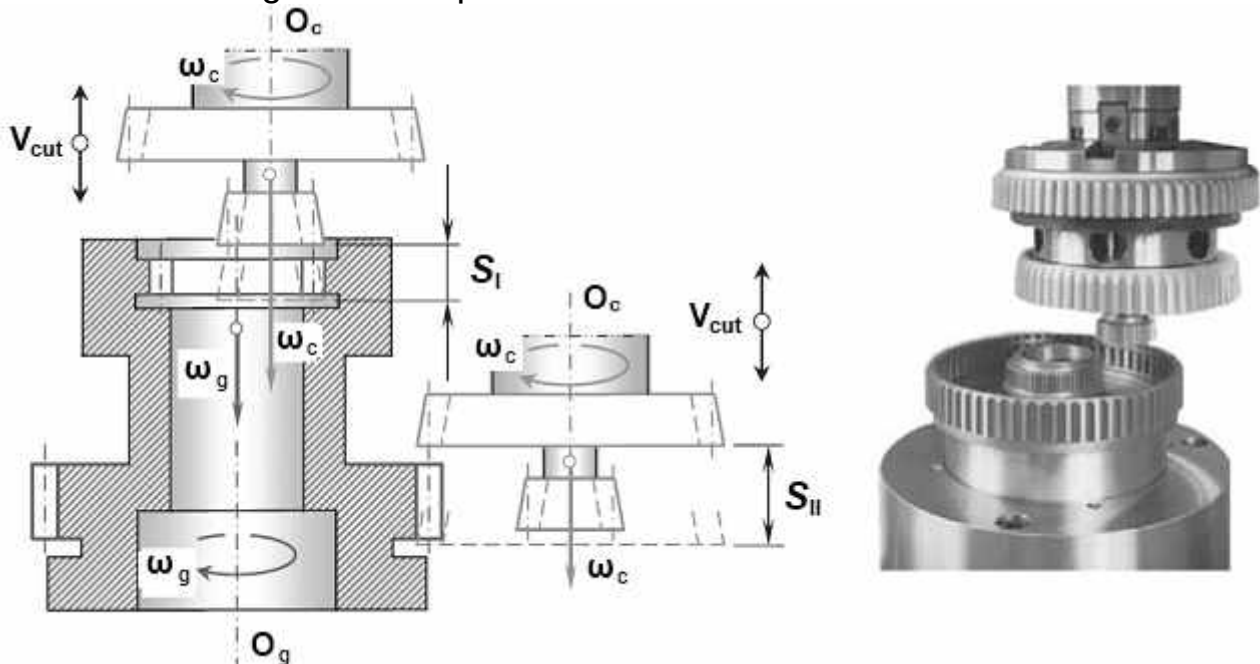


Figure 24 – Consecutive cutting of an internal gear and an external gear in the same machine cycle

In the gear shaping operation, cutting is accomplished by feeding the shaper cutter radially into the annulus and the number of cuts required is controlled by the material, the size of the work gear, and the quality expected. It is common practice to finish with a light finishing cut and this may range from about 0.002 to 0.010 in. (0.05–0.25 mm) deep. Internal gears tend to distort easily unless their thickness is substantial. For epicyclic (planetary) gear units, some flexibility in the annulus is beneficial, but during cutting it is necessary to prevent radial deflection by whatever means is most suitable.

Shaping of external gears with enveloping shaper cutters is not often used (Figure 25).

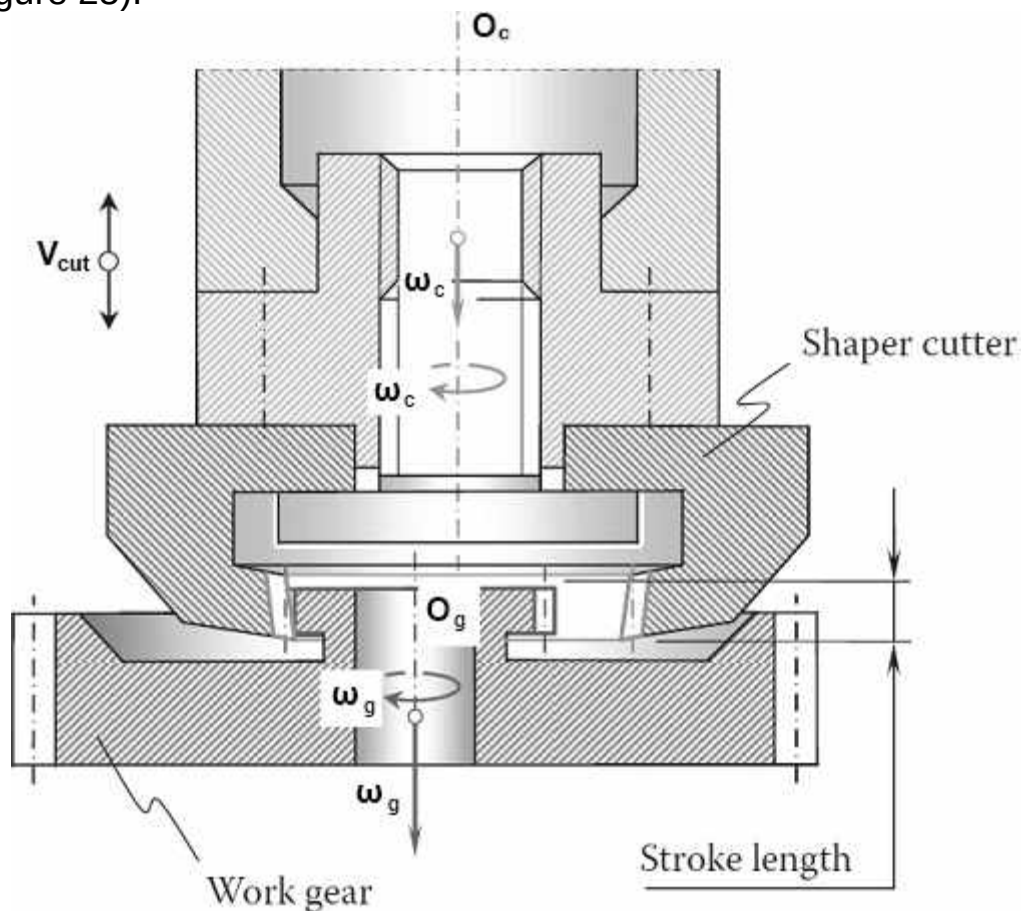


Figure 25 – An enveloping shaper cutter for machining an external gear

However, in some particular cases of gear machining enveloping shaper cutters can be substituted with no gear cutting tool of any other design instead. High cost is the major reason for the limited use of enveloping shaper cutters.

Purpose and scope of the cutters application. Theory

Gear shaper cutter is a set of a large number of elementary gears with infinitely small width of the rim, having respectively positive, zero and negative addendum modification shift and mounted on the same axis in order of decreasing shift values of xm (Figure 26).

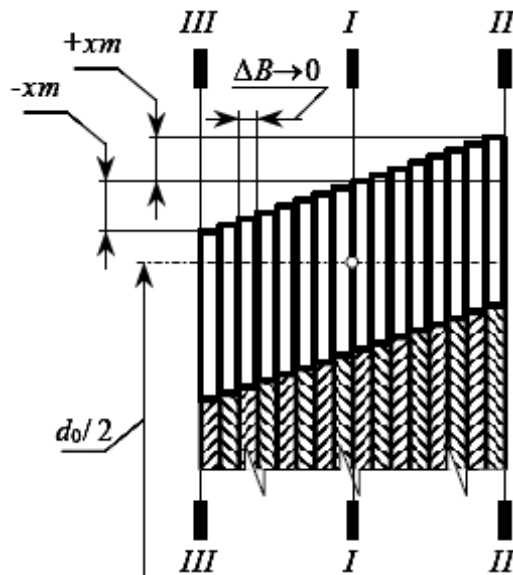


Figure 26 – Addendum modification shift xm

Each of these elementary gears is formed by enveloping movement of rail with profile angle α , and therefore any cutter section perpendicular to its axis has one and the same involute profile. As regrinding the cutter's rake face, one of these infinitely thin gears with the corresponding addendum modification shift value comes into cutting and into engagement with the gear being cut. Therefore, gears formed by various cutter's sections will have the same involute profile.

Thus, the cutter is a corrected gear, having, in general, both positive and negative correction due to the need to ensure its back angle α_a . Front section of the cutter $II-II$ (Figure 27) is called the initial (reference) cross-section, when engaged with the gear it forms a zero transmission.

The distance A from the exposed face $I-I$ of the new cutter to the initial cross section is called the shift of the initial section (addendum) and in the general case is considered as positive shift. In the initial section the initial circle coincides with the pitch circle and the tooth thickness s_0 along the arc of the pitch circle, the size of the head h_{a0} and root h_{r0} of the tooth will be equal to the size of the initial addendum of the cutter rail. Cutter is supplied with rake angle γ_a . Regrinding of the cutter is made by the front surface, as the result of which after each regrinding size A will be reduced, so to improve the life of cutter size A should be chosen as large as possible. But this increases the risk of the teeth tapering, which leads to a decrease in cutter resistance. In addition, the risk of interference of teeth of gears and wheels, cut by this cutter, increases too.

Thus, the first major challenge in the design of cutter is the choice of a suitable shift A . The second task is to choose the distance A_s from the initial section to section $III-III$, which is the boundary of permissible cutter regrinding (see Figure 27) Since with each regrinding diametric dimensions of the cutter decrease, the risk of cutting the sides at the top of the teeth increases and the risk of cut gears and wheels tooth roots undercutting increases too, i.e. it is

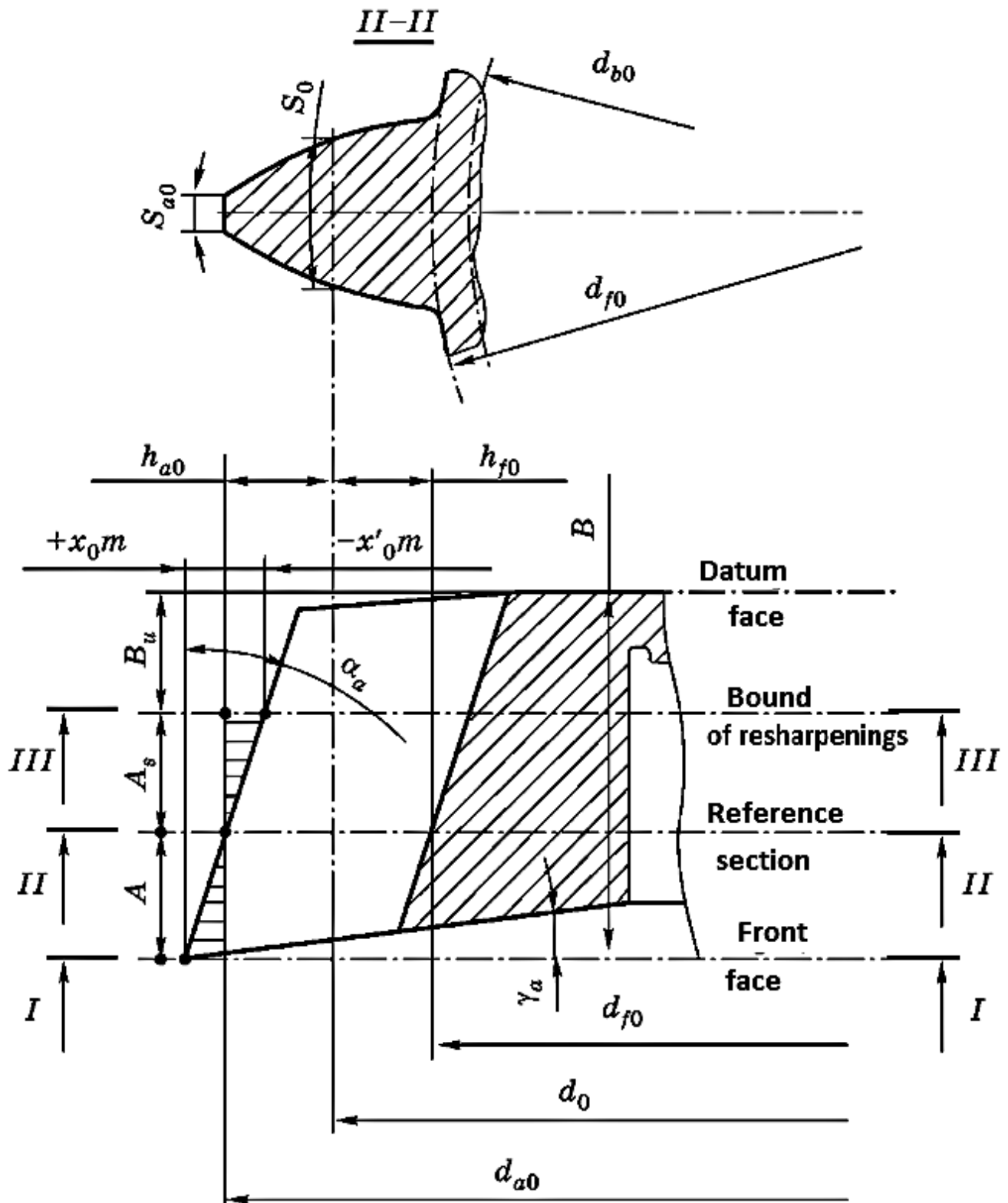


Figure 27 – Positive and negative corrections of gear shaper cutters

necessary to check another four conditions.

Most techniques for solving these problems are following: shift **A** of the initial cross-section is appointed (or calculated by empirical formulas) and check of compliance with the first three conditions for sharpening the cutter

teeth and the absence of interference of teeth of gears and wheels is made. If at least one of these conditions is not satisfied, then the value of A is adjusted and all three conditions are re-checked, and so as long as they all are not met, - as according the artillery principle "overflight-undershoot". The same is repeated for the appointment of the distance A_s , but now for checking the four conditions [2].

By construction, the cutters are divided into: disc-type gear cutters, deep counterbore-type gear cutters and shank-type gear cutters. For cutting spur gears spur-type gear cutters are used, for helical and herringbone – helical gear cutters. Gear cutters are used also for cutting teeth on the block wheels and wheels with collars, internal gears, herringbone gears with continuous tooth without groove to exit the tool, precision gear racks by rounding.

In accordance with GOST 9323-79 gear cutters of the following types are made (Figure 28):

- 1) disc-type spur, accuracy classes AA, A and B;
- 2) disc-type helical, accuracy classes A and B with nominal angles of teeth 15° and 23° ;
- 3) deep counterbore-type spur, accuracy classes AA, A and B with a nominal pitch diameters of 80,100 and 125 mm, as well as accuracy classes A and B with a nominal reference diameter of 50 mm;
- 4) shank-type spur, accuracy classes A and B;
- 5) shank-type helical, accuracy classes B with nominal angles of teeth 15° and 23° .

Cutters of accuracy class AA are designed for cutting gears of 6-th degree of accuracy, and accuracy class A and B, respectively, for the gears of 7-th and 8-th, 11-th degrees of accuracy.

Recommendations on the choice of the basic design elements of finishing disk-type and shank-type spur cutters are shown in Tables 1 and 2 [3].

Performance of gear cutting by gear shaper cutters teeth sectors, gears with narrow rim and a large number of teeth is slightly higher than by the worm cutters. Gear shaper cutters are also advisable to use when cutting gears with module less than 1.5 mm.

Initial data for the design of cutters:

- Materials of processed gears and their hardness;
- Normal gear module m_n ;
- Pressure angle of the gear being cut α ;
- Coefficient of tooth addendum $h_a^* = 1$;
- Coefficient of the radial clearance $c^* = 0.25$;
- Angle of inclination β of the gear tooth and the direction of the tooth;
- Degree of accuracy of the gear being cut and the rate of side clearance;
- Number of teeth of cut gear z_1 and wheel z_2 ;
- Coefficients of the initial addendum modification shift of cut gears x_1 and x_2 .

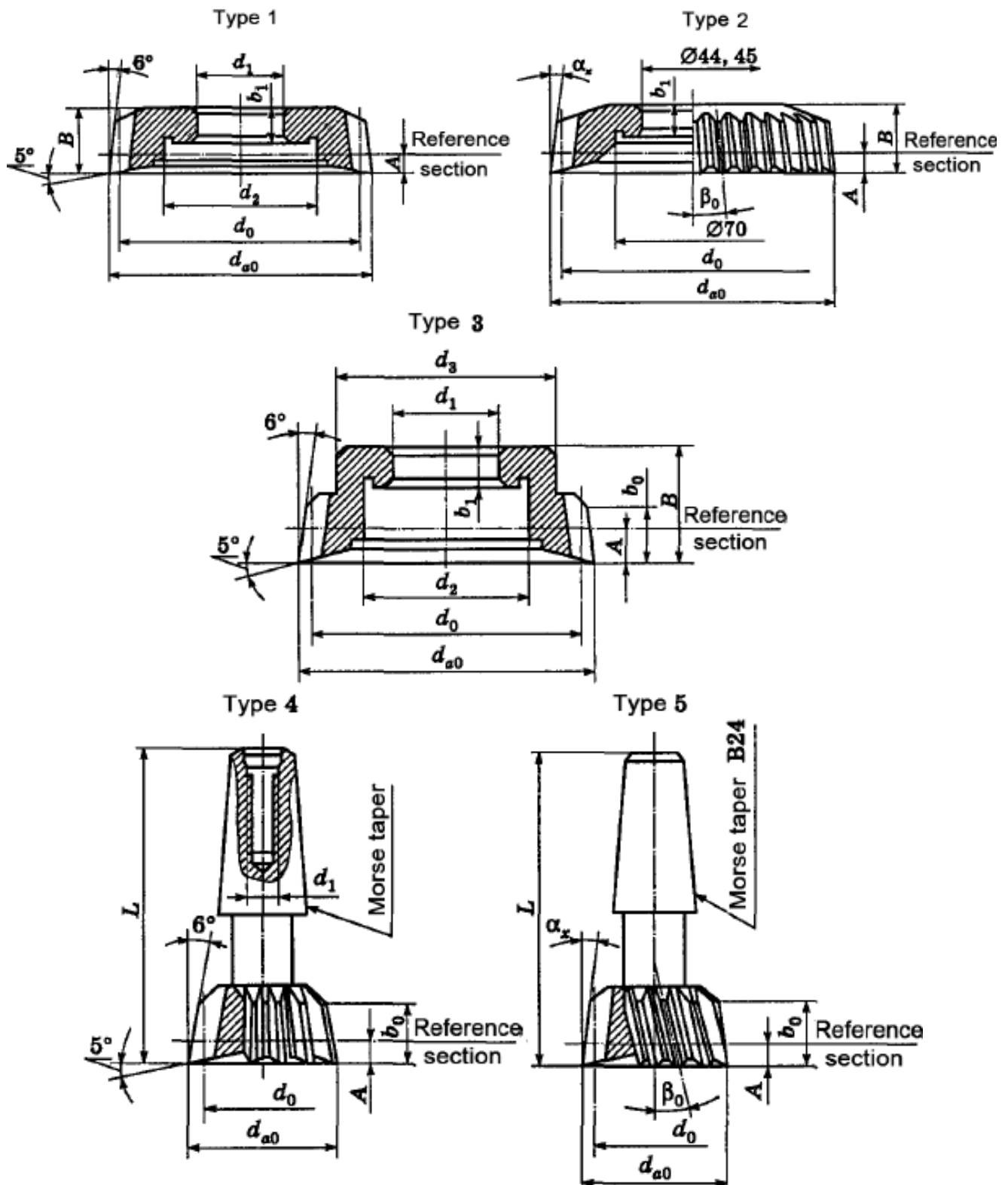


Figure 28 – Types of finishing shaper cutter

Calculation of spur-type gear cutters for cutting external gears

Calculation of spur-type gear cutters for cutting external gears is made in the following sequence.

1. Cutter design and the material of the cutting head are selected consi-

dering the design and physical and mechanical properties of the processed material. The class of cutter accuracy is chosen.

2. Number of cutter teeth z_0 taking into account the nominal reference diameter of the cutter d_{0nom} is d_{0nom}/m_0 . It is rounded to the nearest whole number in accordance with the recommendations of GOST 9323-79 (see Tables 1 and 2) [3].

Table 1 – Recommended basic dimensions of disk-type spur cutters (GOST 9323-79)

m_0 , mm	z_0	d_1 , mm	d_2 , mm	x_0^*	A , mm	b_1 , mm	B , mm
Nominal reference diameter of the cutter $d_{0nom} = 80$ mm							
1,000	76	31,75	50	0,66	6,3	8	12
1,125	67			0,57	6,1		
1,250	60			0,5	5,9		
1,375	56			0,46	6,0		
1,500	50			0,40	5,7		
1,750	43			0,33	5,5		15
2,000	38			0,28	5,3		
2,250	34			0,24	5,1		
2,500	30			0,20	4,8		
2,750	28			0,18	4,7		
3,000	25			0,15	4,3		17
3,250	24			0,14	4,3		
3,500	22			0,12	4,0		
3,750	20			0,10	3,6		
4,000	19			0,09	3,4		
4,250	18			0,08	3,2		
4,500	17			0,07	3,0		
5,000	16			0,06	2,8		
Nominal reference diameter of the cutter $d_{0nom} = 100$ mm							
1,000	100	44,45	70	0,90	8,6	8	17
1,125	90			0,80	8,6		
1,250	80			0,70	8,3		
1,375	73			0,63	8,2		
1,500	68			0,58	8,3		
1,750	58			0,48	8,0		
2,000	50			0,40	7,6	10	20
2,250	45			0,35	7,5		
2,500	40			0,30	7,1		
2,750	36			0,26	6,8		
3,000	34			0,24	6,8		
3,250	31			0,21	6,5		
3,500	28			0,18	6,0		
3,750	27			0,17	6,1		

Table 1, continued

m ₀ , mm	z ₀	d ₁ , mm	d ₂ , mm	x ₀ [*]	A, mm	b ₁ , mm	B, mm
Nominal reference diameter of the cutter d_{0nom} = 100 mm							
4,000	25	44,45	70	0,15	5,7	10	20
4,250	24			0,14	5,7		
4,500	22			0,12	4,8		
5,000	20			0,10	4,3		
5,500	18			0,08	4,2	12	22
6,000	17			0,07	4,0		
6,500	16			0,06	3,7		
7,000	16			0,06	4,0		
8,000	14			0,04	3,0		
Nominal reference diameter of the cutter d_{0nom} = 125 mm							
2,00	62	44,45	80	0,52	9,9	10	22
2,25	56			0,46	9,8		
2,50	50			0,40	9,5		
2,75	46			0,36	9,4		
3,00	42			0,32	9,1		
3,25	38			0,28	8,7		
3,50	36			0,26	8,7		
3,75	34			0,24	8,6		
4,00	31			0,21	8,0	10	24
4,50	28			0,18	7,7		
5,00	25			0,15	7,1	14	28
5,50	23			0,13	6,8		
6,00	21			0,11	6,3		
6,50	19			0,09	5,6		
7,00	18			0,08	5,3		
8,00	16			0,06	4,6		
9,00	14			0,04	3,4		
10,00	14			0,04	3,8		
Nominal reference diameter of the cutter d_{0nom} = 160 mm							
6,0	27	88,9	120	0,17	9,7	16	30
6,5	25			0,15	9,3		
7,0	23			0,13	8,7		
8,0	20			0,10	7,6	20	32
9,0	18			0,08	6,8		
10,0	16			0,06	5,7		
Nominal reference diameter of the cutter d_{0nom} = 200 mm							
8,0	25	101,6	140	0,15	11,4	25	40
9,0	22			0,12	10,3		
10,0	20			0,10	9,5		

Table 1, continued

m_0 , mm	z_0	d_1 , mm	d_2 , mm	x_0^*	A, mm	b_1 , mm	B, mm
Nominal reference diameter of the cutter $d_{0nom} = 200$ mm							
		101,6	140			25	40
11,0	18			0,08	8,4		
12,0	17			0,07	8,0		

Table 2 – Recommended basic dimensions of shank-type spur cutters (GOST 9323-79)

m_0 , mm	z_0	x_0^*	A , mm	b_0 , mm	L , mm	Morse taper	d_1 , mm
Nominal reference diameter of the cutter $d_{0nom} = 25\text{ mm}$							
1,000	26	0,15	1,40	10	80	B18	M10
1,125	23	0,13	1,40				
1,250	20	0,10	1,20				
1,375	18	0,08	1,00				
1,500	18	0,08	1,10				
1,750	14	0,04	0,67	12			
2,000	12	0,02	0,38				
2,250	12	0,02	0,40				
2,500	10	0,00	0,00	15			
2,750	10	0,00	0,00				
3,000	9	-0,01	-0,29				
Nominal reference diameter of the cutter $d_{0nom} = 38\text{ mm}$							
1,000	38	0,28	2,66	12	100	B24	M12
1,125	34	0,24	2,60				
1,250	30	0,20	2,4				
1,375	28	0,18	2,40				
1,500	25	0,15	2,10				
1,750	22	0,12	2,00	15			
2,000	19	0,09	1,70				
2,250	16	0,06	1,30				
2,500	15	0,05	1,20				
2,750	14	0,04	1,00				
3,000	12	0,02	0,60				
3,250	12	0,02	0,60				
3,500	11	0,01	0,33				
3,750	10	0,00	0,00	17			
4,000	10	0,00	0,00				

3. Reference diameter of the cutter is specified $d_0 = z_0 m_0$.

4. For finishing shaper cutters the rake angle is $\gamma_a = 5^\circ$, and for roughing shaper cutters $\gamma_a = 10...15^\circ$.

5. Top-relief angle α_a is recommended to take 6° . It is known, however, that the increase in α_a to $9...12^\circ$ leads to an increase in shaper cutter tool life in

1.3-1.5 times. Shaper cutters with angles $\gamma_a = -15^\circ$ and $\alpha_a = 9^\circ$ for rough cutting of gears have tool life 3...4 times higher than the standard shaper cutters.

6. Actual angle of the shaper cutter profile α_0 is defined up to 1" by the formula

$$\tan \alpha_0 = \frac{\tan \alpha}{1 - \tan \alpha_a \cdot \tan \gamma_a} \quad (56)$$

7. Peripheral relief angle of the cutter section on the reference cylinder (see Figure 29):

$$\tan \alpha_6 = \tan \alpha_0 \cdot \tan \alpha_a \quad (57)$$

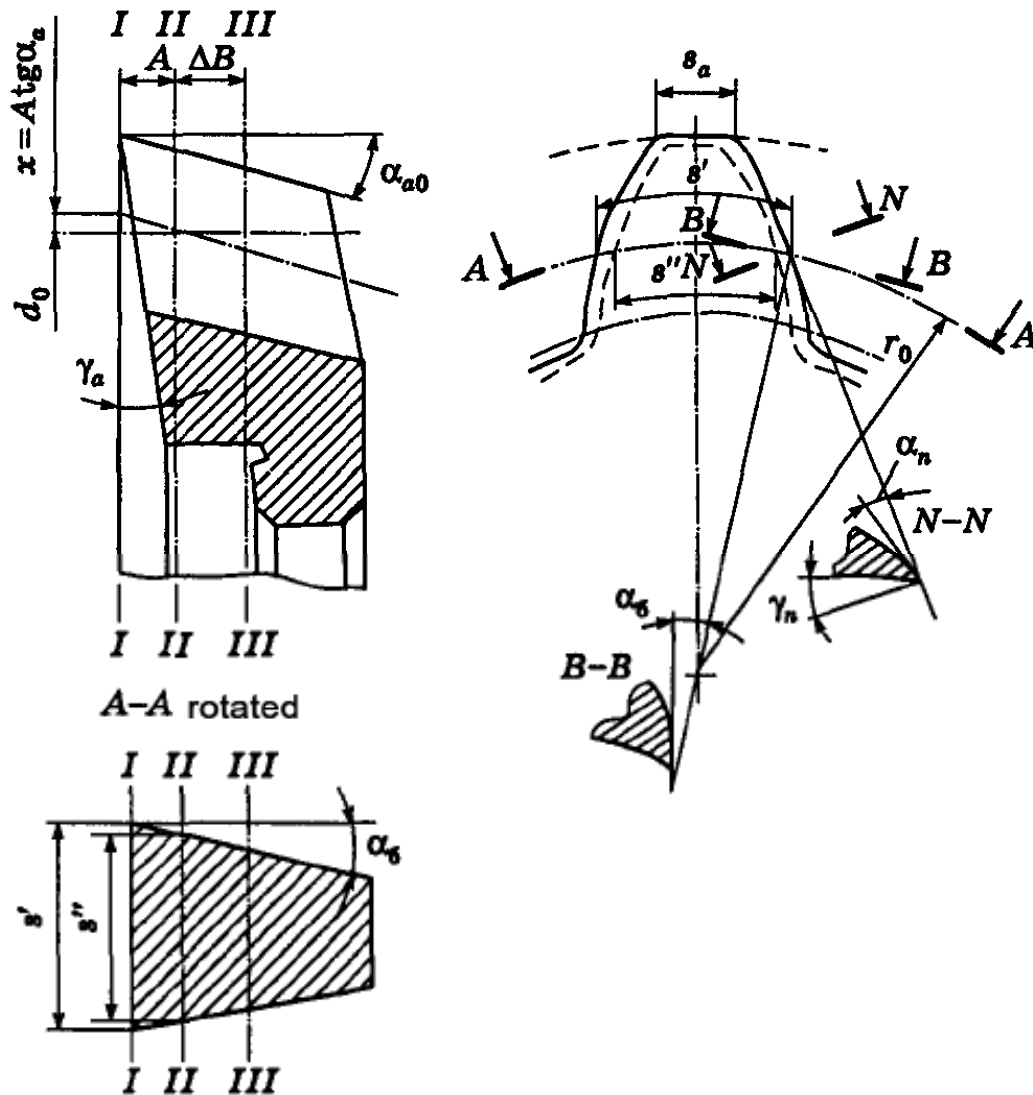


Figure 29 – Gear shaper cutter's geometry

Relief angle α_n on the sides of the teeth in the normal section to profile:

$$\tan \alpha_n = \sin \alpha_0 \cdot \tan \alpha_a. \quad (58)$$

Machine grinding wheel head turns on the angle α_n while grinding shaper cutter teeth, so the specified angle must be obligatory written in the drawings.

For above-mentioned recommended values γ_a , α_a , α the values of α_0 , α_n , α_6 can be taken from Table 3.

Table 3 – Values of α_0 , α_n , α_6 depending on γ_a , α_a , ($\alpha = 20^\circ$)

γ_a	α_a	α_0	α_n	α_6
5°	6°	20°10'14"	2°04'32"	2°12'40"
5°	9°	20°15'30"	3°08'20"	3°20'44"
10°	6°	20°20'49"	2°05'35"	2°13'58"
10°	9°	20°31'38"	3°10'44"	3°23'38"
15°	9°	20°48'43"	3°13'15"	3°26'42"
17°	9°	20°55'53"	3°14'19"	3°28'04"
17°	12°	21°16'09"	4°24'33"	4°43'48"

8. Base diameter of the shaper cutter $d_{b0} = d_0 \cdot \cos \alpha_0$.

Determination of cutter tooth dimensions in the initial section

Dimensions of shaper cutters tooth profile in projection of the front surface on a plane perpendicular to the axis, as well as the dimensions on the profile parameters in a controlled cross-sectional are taken from Annex 1 GOST 9323-79.

Technical requirements for the gear shaper cutters are accepted according to the GOST 9323-79 [4].

9. Shaper cutter tooth thickness on the pitch circle:

for finishing cutters: $s_0 = (\pi m / 2) + \Delta s_y$;

for roughing cutters: $s_0 = (\pi m / 2) - \Delta s_n + \Delta s_y$;

where Δs_n – thinning of the shaper cutter tooth for formation of allowance on the teeth of the gear being cut for post-processing:

- for finish gear milling or gear shaping: $\Delta s_n = \sqrt[3]{m} \cdot \tan \alpha$;

- for grinding $\Delta s_n = 0,5 \cdot \sqrt[3]{m} \cdot \tan \alpha$;

- for gear shaving $\Delta s_n = 0,035 m$.

Δs_y is the value of shaper cutter teeth thickening for formation of side lateral clearance during finishing processing of the cut gears. Values of Δs_y and clearance δs on the thickness of the shaper cutter tooth are taken from Table 4.

Table 4 – The amount of thickening of the tooth Δs_y and tolerance δs the thickness of the tooth cutter, mm

M	Δs_y	δs		m	Δs_y	δs	
		Class A	Class B			Class A	Class B
1,0	0,08	0,02	0,03	4,0	0,10	0,02	0,03
1,25	4,25						
1,75	4,5			0,11	0,03	0,04	
2,0	5,0						
2,25	5,5						
2,5	6,0			0,12			
2,75	6,5						

Table 4, continued

M	Δs_y	δs		m	Δs_y	δs	
		Class A	Class B			Class A	Class B
3,0	0,10			7,0	0,13		
3,25				8,0			
3,5				9,0	0,14		
3,75				10,0	0,15	0,04	0,05

10. Tooth addendum $h_{a0} = h_{f12} = 1,25m$, where h_{f12} is the tooth dedendum of the cut gear and wheel.

11. Tooth dedendum $h_{f0} = h_{a1,2} + c = m + c$, where $h_{a1,2}$ is the tooth addendum of the cut gear and wheel, $c = 0,25m$, if $m \leq 2,5$ mm, and $c = 0,3 m$, if $m > 2,75$ mm.

12. Diameter of the circle of shaper cutter projections in the initial section:

$$d_{a01} = d_0 + 2,5m.$$

13. Shaper cutter tooth thickness on the outer diameter in the initial section

$$s_{a01} = d_{a01} \left(\frac{s_0}{d_0} + \text{inv} \alpha - \text{inv} \alpha_{a0} \right),$$

where $\cos \alpha_{a0} = \frac{d_{b0}}{d_{a01}} = \frac{d_0 \cos \alpha_0}{d_{a01}}$; $\text{inv} \alpha = \text{tg} \alpha - \alpha$ (α is taken in radians).

14. The minimum allowable tooth thickness of the new cutter on the outer diameter by the condition of mechanical strength is $s_{a0} = \sqrt{0,25938m - 0,03752}$.

Approximate values of the allowable teeth thickness on the top of the shaper cutter can be taken by either Table 5 or Figure 30.

Table 5 – Permissible tooth thickness on it's tip

Nominal reference diameter d_0, mm	Module m , mm	Tooth thickness on it's tip s_a , mm
75	1,0...1,5	0,5...0,7
	1,75...2,5	0,8...0,9
	2,75...4,5	1,0...1,1
100	1,0...1,6	0,6...0,7
	1,75...2,5	0,8...0,9
	2,75...4,5	1,0...1,2
	4,5...5,0	1,8...1,4
	5,5...6,0	1,5

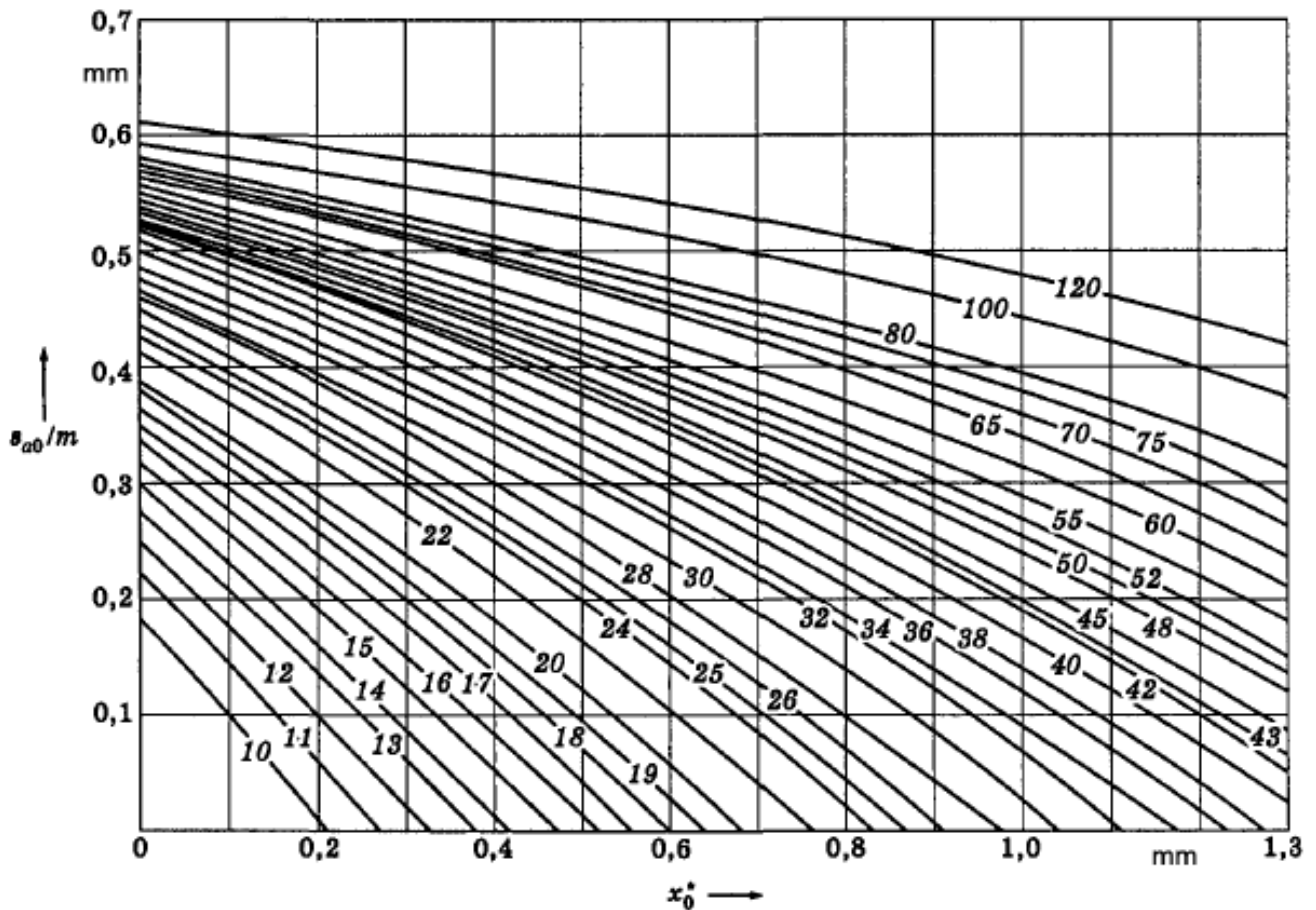


Figure 30 – Nomographic chart of dependence $s_{a0}/m - x_0^*$ (numbers on the nomographic chart corresponds to the number of gear shaper cutter teeth; addendum modification coefficient of gear shaper cutter $x_0 = x_0^*m$)

15. Initial distance, providing a predetermined thickness of the tooth s_{a0} on top:

$$A = \frac{(s_{a01} - s_{a0})d_{a0}}{2 \left(d_{a01} \tan \alpha_{a0} - s_{a01} - \frac{d_{a01}^2}{d_0} \right) \tan \alpha_a}.$$

It is accepted as calculated, if $A < 0,5B$, and equals to $0,5B$, if the calculated $A > 0,5B$, where B – the length of the shaper cutter tooth in accordance with GOST 9323-79.

Initial distance also can be taken according to the relationship

$$A = \frac{x_0^* \cdot m}{\tan \alpha_a},$$

where x_0^* – coefficient of the initial addendum modification shift, taken from Table 1, 3.

The calculated initial distance can be refined and adjusted according to the recommendations of GOST 9323-79 (see Tables 1, 2).

Checking the cutter with the selected initial distance for the absence of

the interference with the transition curves of the cut wheels is performed only for the gear.

There is no interference, if the following condition is met: $\rho_{p1} > \rho_{l1}$, where ρ_{p1} is the radius of curvature of the active profile of the gear tooth at the bottom initial point of contact for its external engagement with wheel:

$$\rho_{p1} = a_{\omega 12} \cdot \sin \alpha_{\omega 12} - r_{b2} \cdot \operatorname{tg} \alpha_{a2},$$

where $r_{b2} = 0,5 m z_2 \cos \alpha$ is the radius of the base circle of the wheel; ρ_{l1} is the radius of curvature of the involute profile of the gear tooth at the point of beginning of the transition curve when cutting it by the shaper cutter (Figure 31).

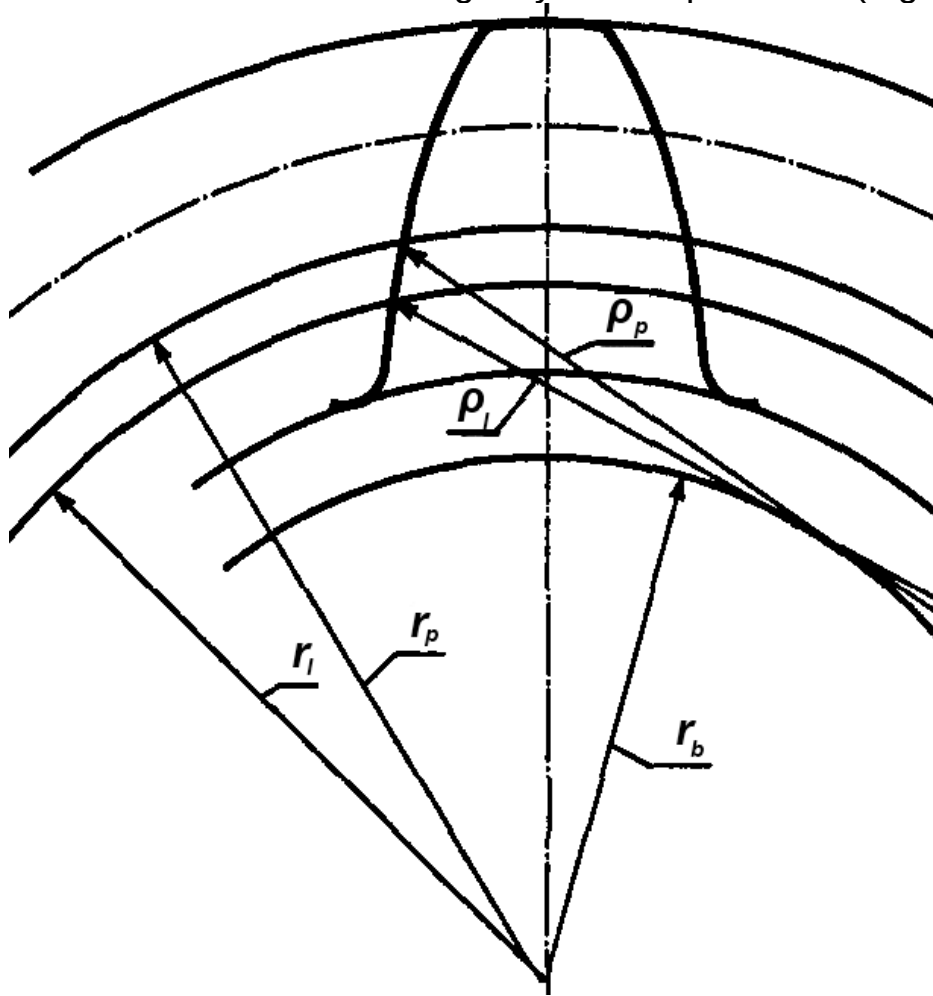


Figure 31 – Scheme for determination of radius of gear's tooth profile curvature

Center distance of the gear drive: $a_{\omega 12} = 0,5 m (z_1 + z_2)$.

Angle α_{a0} of the shaper cutter tooth profile at the point on the circle of the projections is determined according to the formula

$$\cos \alpha_{a0} = \frac{r_0}{r_{a0}} \cos \alpha.$$

For wheel

$$\cos \alpha_{a2} = \frac{r_2}{r_{a2}} \cos \alpha,$$

where r_2 is the radius of the pitch circle of the wheel; r_{a2} is the radius of the wheel top circle.

The value of ρ_{l1} is determined as follows:

$$\rho_{l1} = a_{\omega 10} \cdot \sin \alpha_{\omega 10} - r_{b0} \cdot \tan \alpha_{a0},$$

where r_{b0} is the radius of the base circle of the shaper cutter.

Center distance in the machine gear engagement with gear shaper cutter is

$$a_{\omega 10} = \frac{m(z_1 + z_0) \cos \alpha}{2 \cos \alpha_{\omega 10}}.$$

Angle of engagement $\alpha_{\omega 10}$ in the machine engagement is defined by the formula

$$\text{inv} \alpha_{\omega 10} = \text{inv} \alpha + \frac{2 \tan \alpha (x_1^* + x_0^*)}{z_1 + z_0},$$

where x_1^* , x_0^* are shift coefficients for gear and cutter respectively.

When checking a new cutter x_0^* is taken $x_0^* = x_{0max}^* = \frac{A \cdot \tan \alpha_a}{m}$.

If the condition $\rho_{p1} > \rho_{l1}$ is not satisfied, you can either reduce the value of x_{0max}^* and recalculate the initial distance A , or increase the number of teeth of the gear shaper cutter, and then repeat the check.

Determination of cutter tooth dimensions on the front surface.

These dimensions are determined in the following sequence.

16. Circular tooth thickness s'_0 on a pitch cylinder is counted by the formula

$$s'_0 = s_0 + 2A \cdot \tan \alpha \cdot \tan \alpha_a.$$

17. Gear shaper cutter tooth addendum $h'_{a0} = h_{a0} + A \cdot \tan \alpha_a$.

18. Gear shaper cutter tooth dedendum $h'_{f0} = h_{f0} - A \cdot \tan \alpha_a$.

19. Gear shaper cutter tip diameter $d'_{a0} = d_0 + 2h'_{a0}$.

20. Gear shaper cutter root diameter $d'_{f0} = d_0 - 2h'_{f0}$.

21. Maximum permissible value of cutter re-cutting down ΔB is limited by the strength of the tooth undersized shaper cutter and the lack of teeth undercutting of cut gears: $\Delta B = B - l$, where B is the tooth length of new cutter (adopted in accordance with GOST 9323-79, see Tables 1, 3); l – length of the tooth of completely undersized shaper cutter; it is recommended $l = (1/4 \dots 1/3)B$, but not less than 5 mm.

22. When working with completely undersized shaper cutter, undercutting of gear and wheel tooth dedendum can occur. There is no undercutting, if the following conditions are fulfilled $\rho_{l1} > 0$ (for gear) and $\rho_{l2} > 0$ (for wheel). Calculation of ρ_{l1} and ρ_{l2} is made using the formulas given in section 15, taking

$$x_0^* = x_{0min}^* = \frac{(A - \Delta B) \tan \alpha_a}{m}.$$

23. Test for the absence of the tooth addendum cut-off by completely undersized shaper cutter is made using the ratio $\alpha_{\omega 02} \cdot \sin \alpha_{\omega 02} \geq r_{a2} \cdot \sin \alpha_{a2}$. In this formula, the component values are calculated in the following way:

$$a_{\omega 02} = \frac{m(z_0 + z_2) \cos \alpha}{2 \cos \alpha_{\omega 02}}; \quad \text{inv} \alpha_{\omega 02} = \text{inv} \alpha + \frac{2 \tan \alpha (x_2^* + x_{0min}^*)}{z_2 + z_0},$$

where x_2^* – shift coefficient for the wheel.

24. The remaining elements of shaper cutter design are selected according to GOST 9323-79 (see Tables 1, 3) or for reason of design.

At the reference front face or at the shaper cutter neck the marking is made, which allows to provide its correct setting on the machine and operating conditions:

- trademark of the manufacturer;
- module;
- number of teeth;
- pressure angle;
- accuracy class designation;
- the actual angle of inclination and the helix lead (for helical-type shaper cutters);
- material of the cutting part.

25. Requirements for surface roughness of shaper cutters are shown in Table 6, tolerances and limit deviations of parameters of gear shaper cutters – in Table 7.

Table 6 – Surface roughness of gear shaper cutters, μm (GOST 9323-79)

Surface	Gear shaper cutter's accuracy class		
	AA	A	B
Front and rear surfaces of the teeth, R_z	1,6		2,5
The bearing surface of disc-type and deep counterbore-type gear cutters, R_a	0,2		
Tool bore of disc-type and deep counterbore-type gear cutters, R_a	0,2		
The inner bearing surface of disc-type and deep counterbore-type gear cutters, R_a	0,8		
Shank surface of the shank-type gear cutters, R_a	0,4		0,8
Other, R_a	2,5		

Table 7 – Tolerances and limit deviations of parameters of gear shaper cutters, μm (GOST 9323-79)

Parameter	Designation	Nominal reference diameter, mm		Gear shaper cutter's accuracy class	Module, mm				
					1 to 2	2 to 3,5	3,5 to 6,3	6,3 to 10	> 10
					Tolerances and limit deviations, μm				
Deviation of tool bore diameter	f_d	Fitment bore diameter, mm	up to 50	AA	+4			–	
			50...120		–	+6			
			up to 50	A	+5			–	
			50...120		–	+8			
			up to 20	B	+6		–		
			20...50		+7			–	
			50...120		–	+10			
Cone runout of the shank-type gear cutters	f_{rk}	–		A,B	5			–	
Deviation of perpendicularity of outer bearing surface to the surface of the tool bore	f_{xy}	up to 50	A	4	5	–			
			B	6	8	–			
		50...125	AA	3	4				
			A	5	6				
			B	8	10				
		125...200	AA	–		5			
			A	–		8			
			B	–		12			
		Deviation of parallelism of bearing surfaces	f_x	up to 50	A	5	6	–	
B	8				10	–			
50...125	AA			3	4			–	
	A			5	6			–	
	B			8	10			–	
125...200	AA			–		5			6
	A			–		8			
	B			–		12			
Axial runout of the front surface	f_{yt}			up to 50	A	14			–
		B	20			–			
		50...125	AA	12				–	
			A	16				–	
			B	25					
		125...200	AA	–		20			
			A	–		28			
			B	–		40			
		Deviation of the front and rear angles	f_{ya}	–	AA	$\pm 5'$			
f_{aa}	A		$\pm 8'$						
	B		$\pm 12'$						
	AA		$\pm 3'$						
	A,B		$\pm 5'$						
Runout of addendum circle	f_{rra0}	up to 50	A	12	16		–		
			B	20	25		–		
		50...125	AA	10	12			–	

Table 7, continued

Parameter	Desig- nation	Nominal reference diameter, mm	Gear shaper cutter's accura- cy class	Module, mm					
				1 to 2	2 to 3,5	3,5 to 6,3	6,3 to 10	> 10	
				Tolerances and limit deviations, μm					
Runout of ad- dendum circle	f_{rra0}	50...125	A	16	20		—		
			B	25	32		—		
		125...200	AA	—		16		20	
			A	—		25		32	
			B	—		40		50	
Deviation of addendum cir- cle diameter	f_{da0}	up to 50	A	±320			—		
			B						
		50...200	AA	±3 20	±400		±500	±60 0	
			A	±3 20	±400		±500	±60 0	
			B	±4 00	±500			±60 0	
Profile error of not modified portion of the cutting edge	f_{r0}	—	AA	3	4		6		
			A	4	5	7	10		
			B	8	10	12	16	20	
Deviation of the tooth ad- dendum	f_{ha0}	—	AA, A, B	±1 8	±25	±32	±40	±50	
Adjacent tooth pitch variation	f_{u0}	—	AA	3	4			5	
			A	5	6			8	
			B	8	10			12	
Cumulative	F_{P0}	—	AA	9	11			14	
			A	14	18			22	
			B	20	24	30		36	
Radial runout of the ring gear	F_{r0}	up to 50	A	14		16	—	—	
			B	20	24	26	—	—	
		50...125	AA	12	14			—	
			A	16	18	20		—	
			B	24	26	32		—	
		125...200	AA	—		18		20	
			A	—		24			
		B	—		36		40		

General requirements for the homework

1. Content of the homework

Making the homework students are required to perform the following activities:

a) to design 7 types of various tools with the detailed working out of cutting patterns and design (variants of combination of various types of tools are shown in Table 8);

b) to complete an explanatory note, containing the method of calculation and the necessary calculations for each of the designed tools.

2. Scope of the homework

The student should defend following documentation on homework:

a) graphical part in the amount of 4 ... 5 sheets of A3 or 9 .. 10 A4 sheets (in this case the drawings are filed in the explanatory note);

b) explanatory note in the amount of 30 ... 35 sheets of A4;

Regularity of the homework execution by the students is noted by the lecturer on the front page of the explanatory note.

3. Homework defense

Homework should be defend within the time designated by the department in consultation with the dean's office.

10 ... 15 minutes are provided for defense. In the process of defending student makes a detailed message about the content of the homework, the validity of made decisions and conclusions, and the degree of utilization of science and technology, patent design studies, use of computers for designing. After answering the questions on the content of the homework student gets the mark. Making an assessment of the homework it is taken into account student's knowledge of the homework material, regularity of its implementation, content and literacy of design drawings and notes, the ability to highlight the content of homework and accuracy of answers to the questions, consultant mark.

4. Guidelines for the design of certain types of tools

Initial data for the design are chosen on the variants specified by the department for each student. Variant of the material of an item is selected by the number of student in list of his academic group (or by last digit of the record book).

5. Gear shaper cutters

Variants of tasks for the design of gear shaper cutters (Table 8). The task is to design a gear shaper cutter for spur gear machining. Number of teeth – Z_1 . The gear is to be geared with the spur wheel with Z_2 teeth.

Nominal rack tooth profile is according to GOST 13755-68.

Table 8 – Variants of tasks for the design of gear shaper cutters

Variant number	m	Z_1	X_1	Z_2	X_2	The degree of accuracy in accordance with GOST 1643-72
1	1	35	+0,15	40	-0,15	7-7-6-Ba
2	1,25	30	+0,1	42	+0,1	7-Bc
3	1,25	28	+0,1	35	+0,1	6-7-8-Ba
4	1,375	27	+0,15	36	-0,1	7-Ba
5	1,5	24	+0,1	30	+0,1	6-6-7-Ba
6	1,75	25	+0,15	30	+0,1	7-8-8-Ba

Table 8, continued

Variant number	m	Z_1	X_1	Z_2	X_2	The degree of accuracy in accordance with GOST 1643-72
7	2,0	23	+0,15	32	-0,1	6-7-8-Ba
8	2,25	28	+0,2	35	+0,2	7-7-8 Дв
9	2,5	25	+0,15	40	+0,3	6-7-7 Ca
10	2,75	24	+0,2	32	+0,15	6-7-8 Bc
11	3,0	23	+0,25	38	+0,3	8-Ca
12	3,5	22	+0,15	28	+0,2	7-Ba
13	4	20	+0,1	32	+0,25	6-Ca
14	4,5	19	+0,1	30	+0,25	7-7-8-Ba
15	5,0	18	+0,1	35	+0,25	7-6-7-Да
16	5,5	17	0	27	+0,2	6-7-8-Ba
17	6	20	+0,15	45	+0,3	7-6-7-Ca
18	7	19	0,1	28	+0,2	8-7-6-Ba
19	8	18	0	36	+0,3	7-Ba
20	9	17	0	25	+0,2	6-Ca

Calculation of gear shaper cutter must precede the determination of additional initial data for the part by calculation or reference literature: the thickness of the wheel tooth being cut, outside diameter and root diameter, the value of tolerances on both parameters, depending on the degree of accuracy (see Table 8).

Reference circle diameter of the gear shaper cutter appointed on the basis of the cut gear module and machine model, which will be used. The value of reference circle diameter should be aligned with the standard value. The next step is to define the parameters of the tooth in the reference section and finding the initial distance. Designed gear shaper cutter is checked for correctness of wheel tooth cutting - no profile interference, flanking and topping off.

In case of failure of any conditions initial distance should be changed or the number of teeth of the cutter or grinding limit.

A working drawing gear-cutting cutter is performed.

Technical requirements

Necessary information that is impossible or inappropriate to express graphically or by symbolic notation include the text part of the drawing - the technical requirements and is positioned above the title block. On sheets of A3 format more text can be placed in two or more columns. The width of the columns should be no more than 180-185 mm.

The headings "Technical requirements" and "Technical regulations " are placed above the appropriate text and do not underlined. If placed in the drawing only the technical requirements, the title "Technical Requirements" do not written.

Paragraph numbering is carried out in Arabic numerals with the point after. Description of the item starts with a capital letter and ends with a period. Text requirements should be short and precise. Abbreviations other than generally accepted, not tolerated.

Homogeneous and similar in character requirements are grouped in the following sequence:

a) requirements to workpiece, heat treatment, hardness, electrical, magnetic and other properties of the material; here indicate, if necessary, substitute materials;

b) the dimensions and tolerances; deviations of form and relative position of surfaces, dimensions for reference;

c) gaps that define the layout design;

d) requirements for setting up and adjusting the part;

e) special requirements: noiselessness, vibration, etc .;

f) conditions and test methods;

g) the guidance on branding and labeling,

h) the rules of transportation and storage,

i) the special conditions;

j) the necessary links to other documents.

Each item in the specifications written on a new line.

To protect the course project on the subject "Tool provision of aircraft engines manufacture" students should have good attendance (at least 50 %) on lectures, laboratory and practical classes, perform an individual task for the design of tools, which is confirmed by relevant drawings and explanatory notes thereto. Note the individual conclusions to the explanatory note and the statements documentation. In addition, it is necessary to be prepared to defense the course project using the existing students notes.

Example of the statements documentation is shown in Table 9 below.

Table 9 – Example of the statements documentation

No	Page format	Legend	Name	Number of pages	Notes

Bibliographic list

1. Radzevich, S. P. Gear cutting tools: fundamentals of design and computation [Text]/ Stephen P. Radzevich. – Taylor and Francis Group, LLC, 2010. – 788 p.
2. Панкратов, Ю. М. САПР режущих инструментов [Текст]: учеб. пособие. – СПб.: Лань, 2013. – 336 с.
3. Фельдштейн, Е. Э. Металлорежущие инструменты [Текст]: справочник конструктора / Е. Э. Фельдштейн, М. А. Корниевич. – Минск: Новое знание, 2009. – 1039 с.
4. Нефедов, Н. А. Задачи по проектированию режущего инструмента [Текст] / Н. А. Нефедов, К. А. Осипов. – Л.: Машиностроение, 1990. – 328 с.
5. Фельдштейн, Е. Э. Режущий инструмент. Курсовое и дипломное проектирование [Текст]: учеб. пособие / Е. Э. Фельдштейн. – Минск: Дизайн ПРО, 2002. – 320 с.
6. Кишуров, В. М. Курсовое проектирование режущего инструмента в машиностроении [Текст]: учеб. пособие / В. М. Кишуров, П. П. Черников. – М.: Изд-во МАИ, 2006. – 159 с.

Навчальне видання

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**ІНСТРУМЕНТАЛЬНЕ ЗАБЕЗПЕЧЕННЯ ВИРОБНИЦТВА АВІАЦІЙНИХ
ДВИГУНІВ.
ПРОЕКТУВАННЯ ДОВБАЧІВ**

(Англійською мовою)

Редактор А. В. Галкін
Технічний редактор Л. О. Кузьменко

Зв. план, 2015

Підписано до друку 08.05.2015

Формат 60x84 1/16. Папір офс. № 2. Офс. друк

Ум. друк. арк. 3,4. Обл.-вид. арк. 3,87. Наклад 100 пр.

Замовлення 173. Ціна вільна

Видавець і виготовлювач

Національний аерокосмічний університет ім. М. Є. Жуковського

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Свідоцтво про внесення суб'єкта видавничої справи
до Державного реєстру видавців, виготовлювачів і розповсюджувачів
видавничої продукції сер. ДК № 391 від 30.03.2001