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FORM TOOL DESIGNING

Educational aid

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F76

Розглянуто графічні й аналітичні методи визначення профілю різців, а також розрахунок похибок оброблення фасонними різцями. Показано етапи проектування фасонних різців, наведено дані для виконання розрахунково-графічних завдань, лабораторних робіт, 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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Graphic and analytic methods of form tool profile determination are covered in this educational aid, as well as estimation of working errors for form tool. Stages of form tool 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.

Fig. 25. Tables 11. Bibliogr.: 8 titles

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Calculation and design of turning form tool

Form tools are used for the machining both internal and external surfaces and there are a variety of types. They are used in mass, serial, and sometimes in single-piece production.

According to the principle of work, turning form cutters could be of two types: radial and tangential. Depending on the flank form and design features, there could be different types of form tool: circular, flat and bar; sometimes helical cutters are used (see Figure 1).

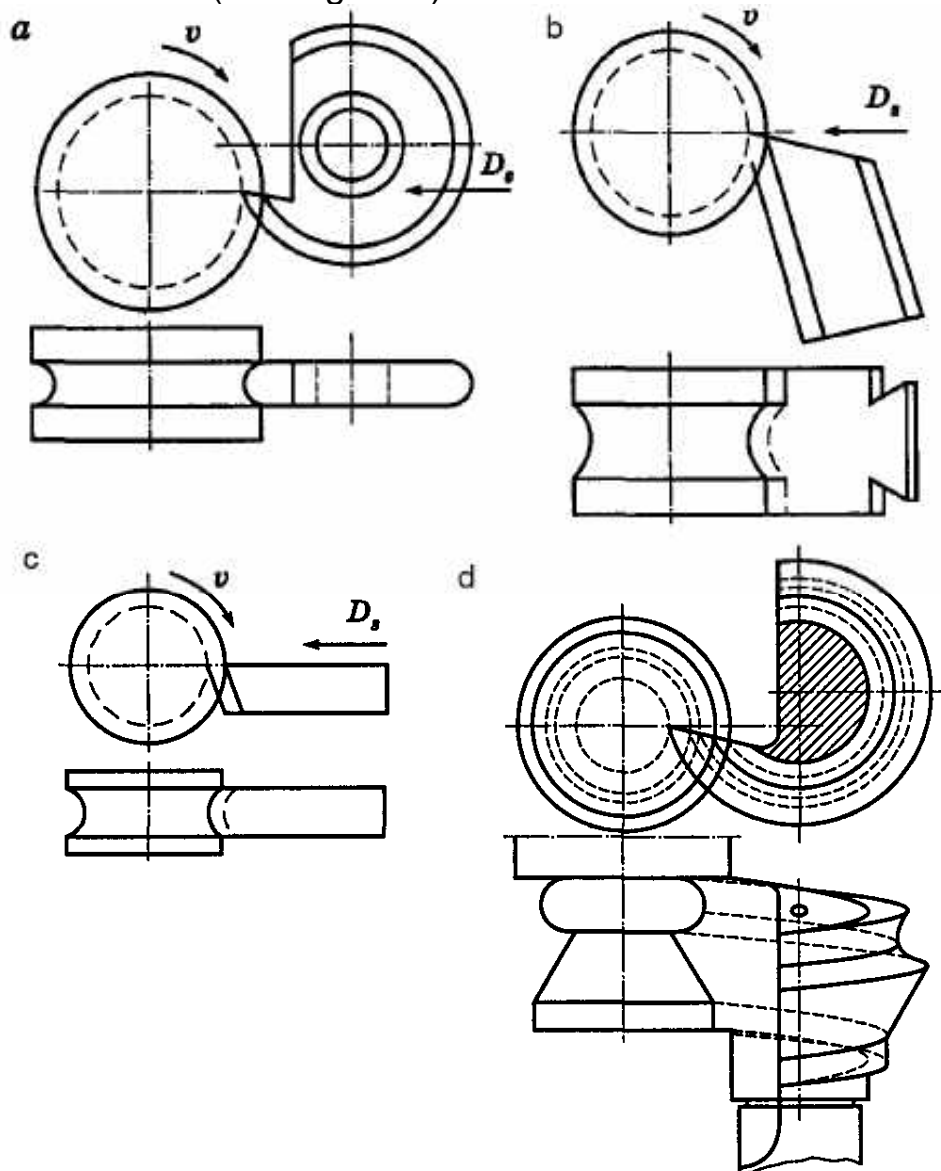


Figure 1 – Form tool classification according to their design:
a – circular; b – flat; c – bar; d – helical

The bar form tool are like common lathe tool, but have a form cutting edge, that corresponds to the configuration of the part's surface. This type of tool tolerate a small amount of regrinding and is used in single-piece and small-

scale production. They are fixed in the carriage in the same manner as conventional cutters.

Flat form tool is a prism, one of whose lateral faces - shaped surface and one of its ends - the face. The tool clearance on the form cutting edge are provided by its mounting in the tool holder and the tool rakes – by its grinding [1].

The working parts of bar and prismatic cutters are made of high-speed steel and tool holders are made of construction steel. Moreover, to save high-speed steel cutting part is often welded.

Circular form tool is body of revolution with the angular groove cutout to create face and space for the chip.

The round shaped cutters are widely used due to relative simplicity of their manufacture and their durability (a large number of resharpening is allowed).

Recently, while hard-to-machine materials machining hard-facing alloy cutting tool is used more often despite the complexity of their grinding especially if cutting tool profile is complex.

The dimensions of working part and the height of the cutting tool profile will be equal to the corresponding sizes and height of the machined surface profile when the angles α and γ are equal to zero (see Figure 2).

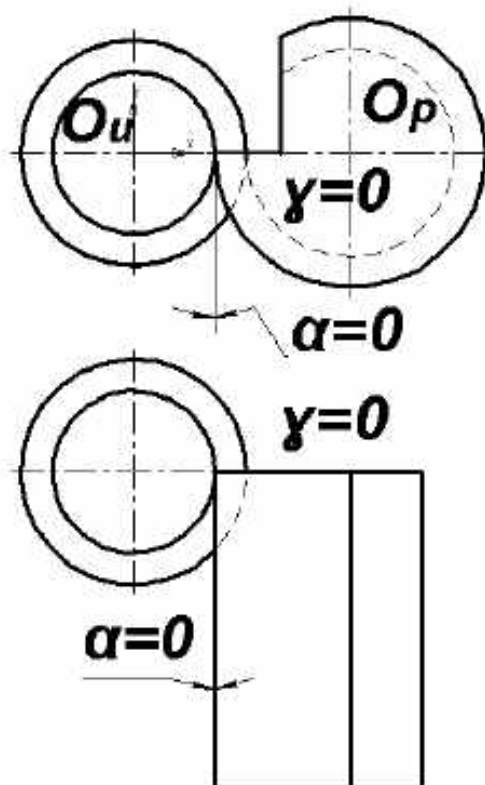


Figure 2 – Circular and flat form tool mounting when $\alpha = 0$ and $\gamma = 0$.

However, such geometrical parameters aren't practically used because cutting in that case is almost impossible. The cutters are sharpened and

mounted to provide positive value of rake and back angles. The rake angle, as prismatic as the round cutter is provided by sharpening. The back corner of the round cutter is created by the displacement of the center of cutter at size h_p . But at the prismatic cutter the back angle is created by its inclination [2].

In practice cutters with a parallel arrangement of an axis of rather processed detail gained distribution. If the detail configuration on separate sites of a profile doesn't provide minimum necessary back angles at parallel arrangement, the inclined arrangement of an axis will be applied.

The profile of the detail measured along an axis ($l_1, l_2... l_n$), in accuracy corresponds to cutter profile with axis parallel arrangement of rather processed detail. For performance of necessary height and form of profile the corresponding correctional calculations of tool profile should be made.

There are two ways: graphic and analytical. The graphic is carried out by rules of projective plotting and is described in [3]. Then it is recommended to use *KOMПAC CAD* system.

Design stages of form tool

Design of shaped cutters consists of the following main stages:

- 1) preparation of detail drawing for calculation of shaped cutter;
- 2) choice of cutter type;
- 3) definition of angles of cutting part and angles of cutter installation;
- 4) determination of the overall and addition dimensions of cutter;
- 5) calculation of the sizes of cutter profile (correctional calculation of cutter);
- 6) calculation of allowances on the profile sizes, corners of sharpening and cutter installation;
- 7) drawing up a working drawing of a cutter;
- 8) pattern design for control of cutter profile at its production and a counterpart for template check;
- 9) support design for cutter fastening on the machine.

Preparation of detail drawing for calculation of shaped cutter. For calculation of the sizes of cutter profile it is necessary to set the settlement or theoretical sizes of a workpiece. When processing workpiece each size could be received easier in the tolerance zone, its average sizes are accepted to the theoretical sizes of workpiece. For example, the shaft is set by diameter $50_{-0,100}^{-0,032}$.

Then average in tolerance zone the size of shaft diameter will be 49,934 mm, and calculated value of radius 24,967 mm. If the size costs on the drawing without the admission, it is accepted on 10... 11 accuracy grades; sign of deviations in this case "+" for the enclosing sizes, "-" for enclosed, "+" for the other sizes. As a rule, longitudinal sizes of profile and radiuses of arc sites are accepted with deviations «±» therefore their face values can be taken for nominal value.

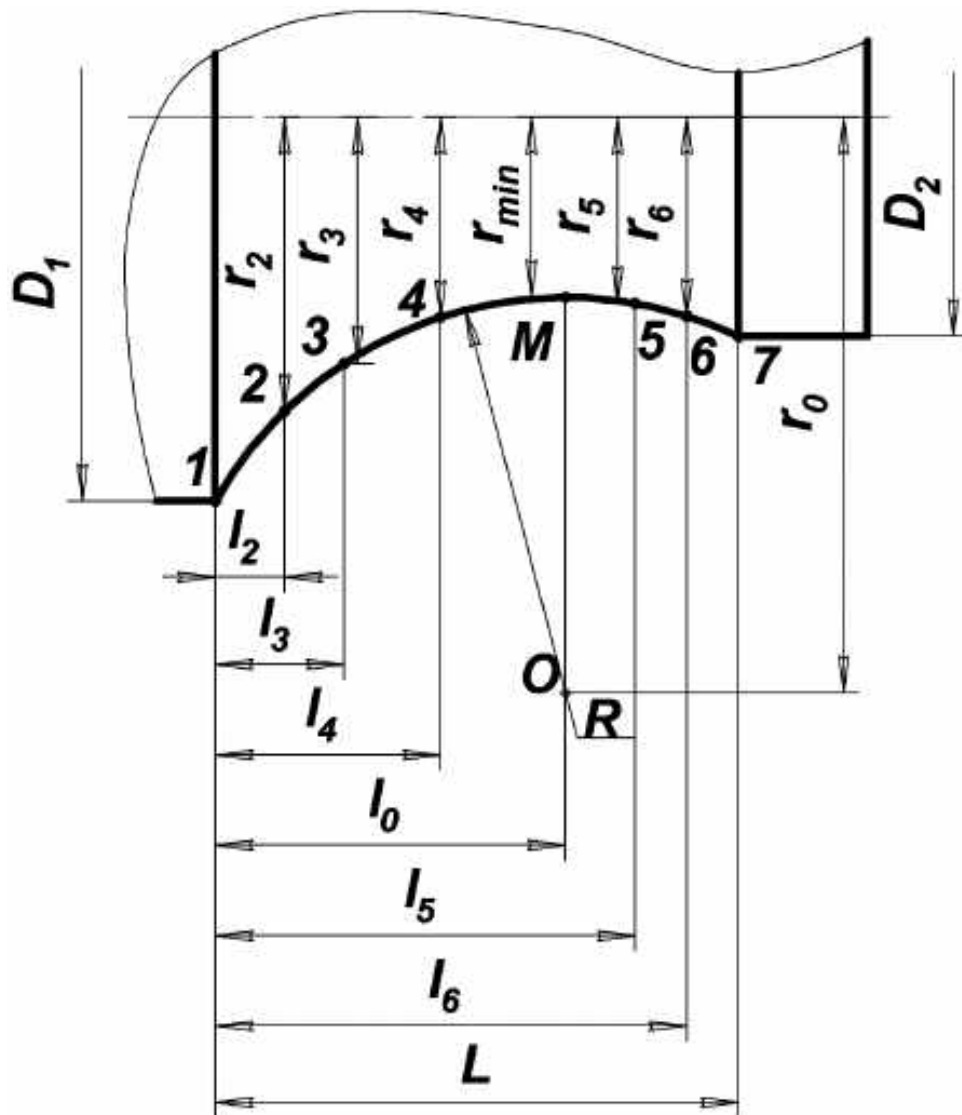


Figure 3 – Scheme for determination of intermediate points radiuses on parts arcwise section

The greatest difficulty is presented by determination of radiuses of arc sections intermediate points. In this case by the set theoretical D_1 , D_2 , L , R sizes, and lengths l_2 , l_3 , ... l_6 , (Figure 3) find radiuses of points 2 ... 6, i.e. r_2 , r_3 , ... r_6 . In certain cases it is necessary also to determine the smallest radius of r_{min} of point M . At the beginning for the solution of these questions it is necessary to find coordinates of the circle center l_0 and r_0 that is made on trigonometrical dependences.

In case it isn't required high precision of detail processing, the similar sizes could be determined graphically (profile drawing in a big scale). It is recommended to check results graphically in order to avoid gross blunders at analytical calculation.

The solution of question on additional edges of form cutter is connected with that often form cutters except processing, the set profile also remove a facet from a detail butt and cut a flute for simplification of a detachable cutter work (Figure 4).

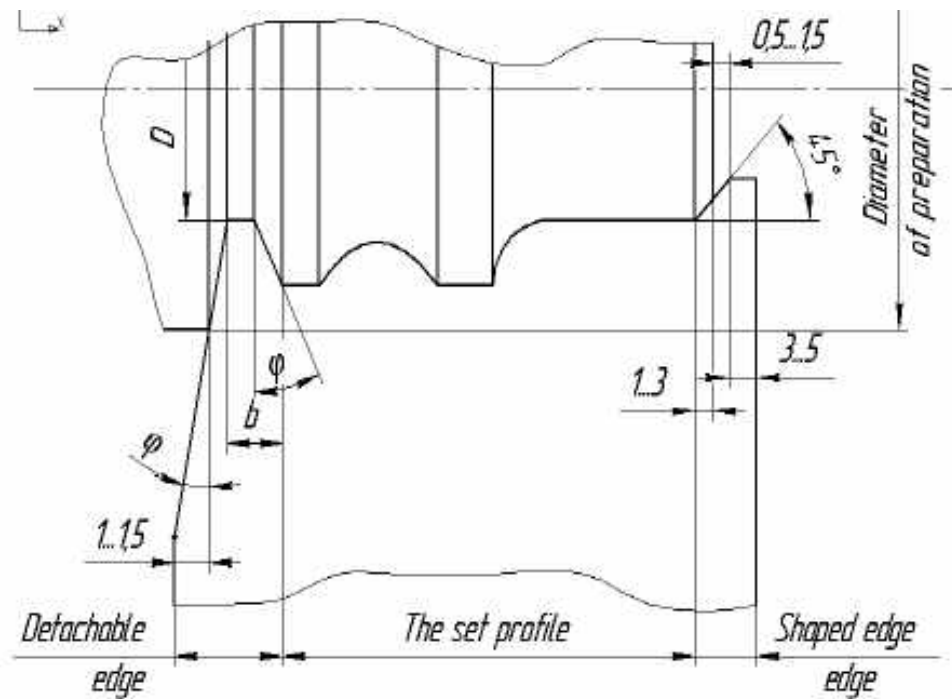


Figure 4 – Additional edges of form tool

Flute diameter D shouldn't be less than the smallest detail diameter D_{min} and depends on detail rigidity and its configuration. In other words, parting-off cutting edge shouldn't extend beyond cutter working profile. The size b is slightly bigger or equal to width of part-off cutter, corner $\varphi = 15... 20^\circ$. Further at cutter designing all profile together with additional edges is taken into account. To exclude grinding of a back surface of a part-off edge, the point "C" should be located below all points of cutter profile.

Choice of shaped cutter type. Under production conditions the detail drawing is typical initial data for form cutters design. To choose the right form cutter for part processing engineers are guided by the following reasons.

Prismatic form cutters are used only for external processing. Big rigidity of their fastening in support with the help of "swallow tail" allows to work with big giving or to conduct processing profiles of bigger length at increased requirements to the accuracy of the sizes and processed detail profile.

Rod cutting tools are used at single-unit production and small-scale production of details. They could be resharpened a few times and demand corrective maintenance at height by means of strips after each resharpening. In other cases round (disk) cutting tools are applied. They suppose greater amount of resharpenings and more workable. Besides round shaped cutting tools could process internal contours.

Cutting tools of radial type is used more often. The reason is that the majority of lathes slides has such a design, in which cutting tool installed at height of detail axis. Cutting tools of tangential type can be applied at small depth of detail shaped section ($t_{max} < 0,12D$), however, it is necessary to consider possibilities of arranging and fixing of such cutting tool on lathe.

Essential advantage of tangential cutting tool is possibility of machining of details of different diameter with identical shaped sections both gradual incision and a cutting tool exit that carries on to reduction of cutting efforts and allows to process nonrigid details, within 0,03 mm for diameter. However capacity of handling at their use more low than at operation of cutting tools of radial type.

Cutting tools with double inclination of front surface when λ and $\gamma \neq 0$, apply at machining of the profiles having conical element of extended precision.

Cutting tools with special installation (with the torn base of fixation or the inclined body) serve for improvement of machining conditions for face of workpart as the clearance angle α_N is thus increased. ψ° turn of the base is applied to all cutting tools; the side inclination of the body on an edge α_b is typical for prismatic cutting tools. The side rake is more favorable than the base turn as diminishes holder dimensions and increases its ruggedness in comparison with holder at $\psi \neq 0$. During internal machining to increase in edges α_N on face blades also apply screw-shaped cutting tools.

Round cutting tools often made the bore type; at small dimensions of cutting tool (usually for boring) apply tail cutting tools. Round cutting tools, as a rule, is solid and made of quick cutting steel. The prismatic cutting tool of big sizes are made in brazed or welded. The cutting part material of cutting tool is selected with account for cutting conditions (workpart material, machining conditions, rigidity of technological system).

Definition of cutting part edges. Cutting tool edges γ and α are preset at the most exposed (base) point determined in cutting tools of radial type at height of detail axis, in section by plain, perpendicular to the cutting tool fastening base. At cutting tool with side rake of the body ($\alpha_b \neq 0$) these edges are set in section, perpendicular to workpiece axis. According to recommendations [7] accept following magnitudes of front rakes of shaped cutting tools (Table 1).

Table 1 – Tool rakes of form tool

Work material	Mechanical properties				Tool rake, degrees
	ultimate strength σ_s , MPa		hardness HB		
	min.	max.	min.	max.	
Copper, aluminium	–	–	–	–	20...25
Steel		500		150	25
Steel	500	800	150	235	20...25
Steel	800	1000	235	290	12...20
Steel	1000	1200	290	350	8...12
Bronze, leaded brass					0...5
Cast iron				150	15
Cast iron			150	200	12
Cast iron			200	250	8

By analogy, angles α and γ of flat and circular form tool changes in the direction of tool holder. Tool clearance is chosen accordingly to the

characteristics of form tool. When tool clearance is big, cutting edge becomes weaker, when it is too small – friction forces are increasing between the clearance face and transient surface of the workpiece.

It is possible to do a clearance angle of prismatic cutting tools more than at the round. Usually $\alpha = 8..12^\circ$ for round and $10..15^\circ$ for prismatic cutting tools. It is necessary to mean that clearance angles variable in different points of an edge. In section, normal to projection of cutting edge to the basic plain, they can be on some sites of much less nominal value. Therefore it is necessary to produce inspection of minimum magnitude of clearance angle using the formula

$$\operatorname{tg} \alpha_N = \frac{D}{D_x} \cdot \operatorname{tg} \alpha_T \cdot \sin \varphi,$$

where α_T - a clearance angle in the given point in face section; φ - an edge between a tangent to a detail profile in the given point and a face plain of a detail; D and D_x - accordingly the greatest diameter and diameter of a cutting tool in a point X ; for prismatic cutting tools $D/D_x = 1$. The edge α_N should not be less than 3° .

Usually on sites of blades perpendicular to base of cutting tool undercuts are done at an angle φ_1 to $3..4^\circ$ or chamfers are left with breadth about $0,5..1,0$ mm (Figure 5).

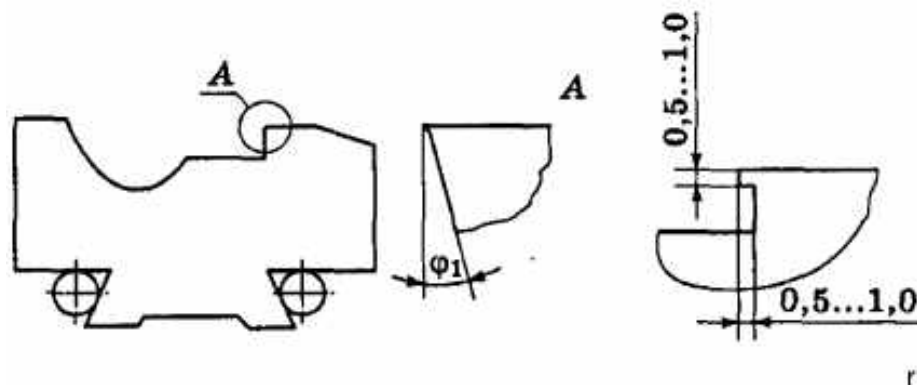


Figure 5 – Structural variations of edges, perpendicular to the cutter's base

In case of designing the cutting tool with the angle $\lambda \neq 0$, side cutting-edge angle λ_0 is calculated depending on the positions of the base line (part of the cutting edge, adjusted on height of workpiece axis) by the formula

$$\operatorname{tg} \lambda_0 = \operatorname{tg} \sigma \sin \gamma,$$

where σ - the angle between the base line and the workpiece axis. This formula can be used only for cutting tools of typical installation.

Determination of overall and mounting cutting tool dimensions.

Usually overall and mounting dimensions of the cutting tools are determined from design considerations, depending on the depth of the shaped profile of an item t_{\max} and the profile length L .

The outer radius of the circular form tools (Figure 6) is calculated by the formula

$$R = \frac{t_{max} + e + K + \frac{d_0}{2}}{\cos \alpha}$$

where e – face sharpening depth, needed to accommodate the chip, K – thickness of the cutter body, which is necessary to provide strength, $K = 8 \dots 10$ mm; d_0 - diameter of the tool bore; α - relief angle.

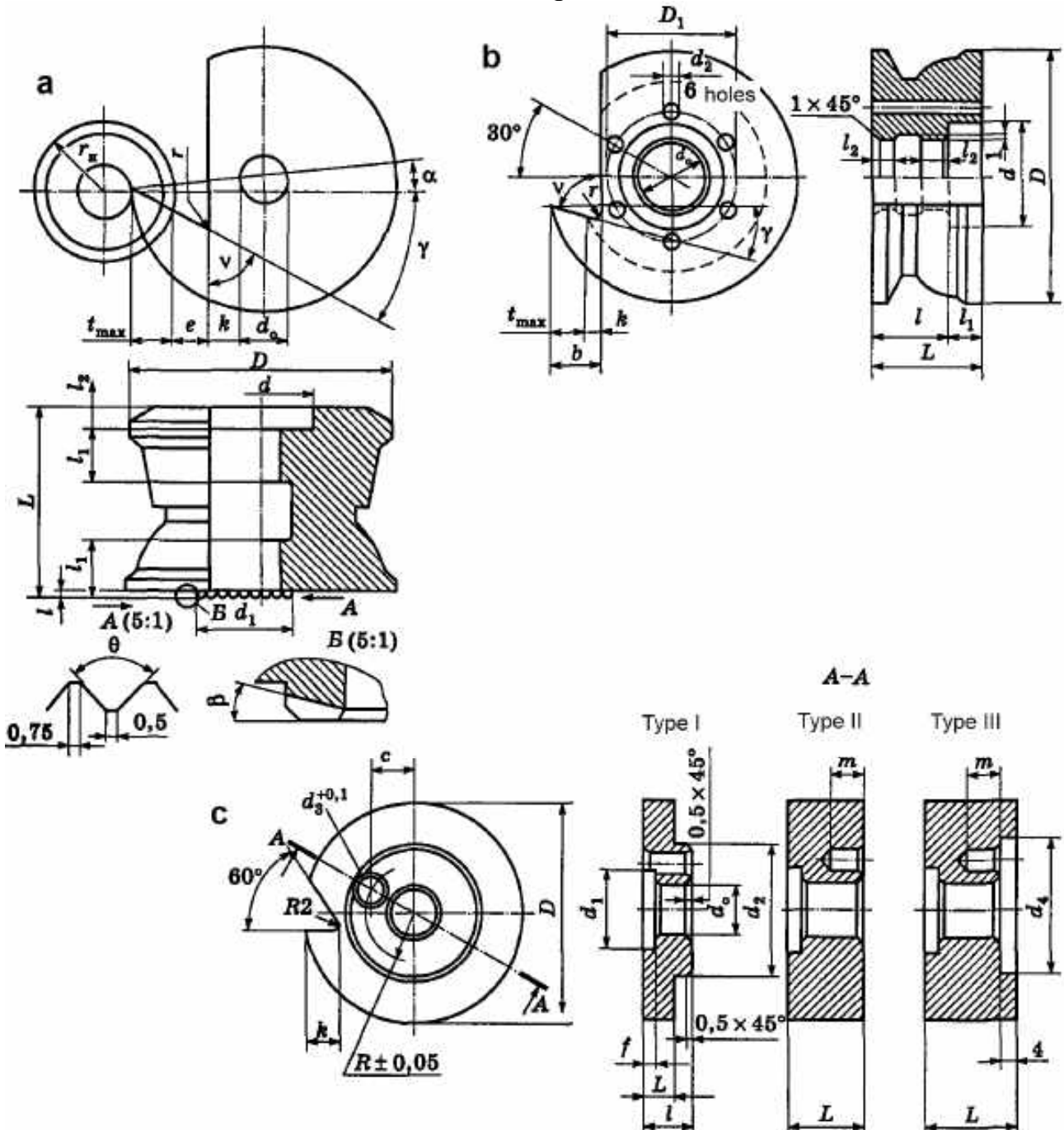


Figure 6 – Overall and mounting dimensions of different types of circular form tool for external work

Mounting bore diameter is calculated as follows:

$$d_0 = \sqrt[3]{\frac{M_e}{0,1[\sigma]_u}},$$

where M_e - equivalent bending moment, $N \cdot m$; $[\sigma]_u = 200 \dots 250$ MPa - allowable bending stress of the mandrel material.

With cantilever restrained circular form tool:

$$M_e \approx 0,5 \sqrt{(RL)^2 + (P_z D)^2},$$

at double-sided restraint:

$$M_e \approx 0,25 \sqrt{0,25(RL)^2 + (P_z D)^2},$$

where $R = \sqrt{P_z^2 + P_y^2}$; P_z, P_y -, main and radial component of the cutting force respectively, determined by reference books.

In practice, the values of e and d_0 are selected depending on the profile depth of an item t_{max} according to the Table 2.

Table 2 – Magnitude of e and d_0 of circular form tool for external work (mm)

Part's form profile depth t_{max}	e	d_0
up to 6	3	13
up to 8	3	16
up to 14	4	22
up to 25	5	27

The largest diameter of the cutting tool $D_H = 2R$ is rounded up to the values from the normal row of linear dimensions according to the OST 6636-69.

Structural dimensions of the cutting tool (Figure 7) can be chosen depending on the profile depth of an item. The diameter D_H is usually in 6 ... 8 times greater the profile depth. These data are presented in Tables 3 – 5.

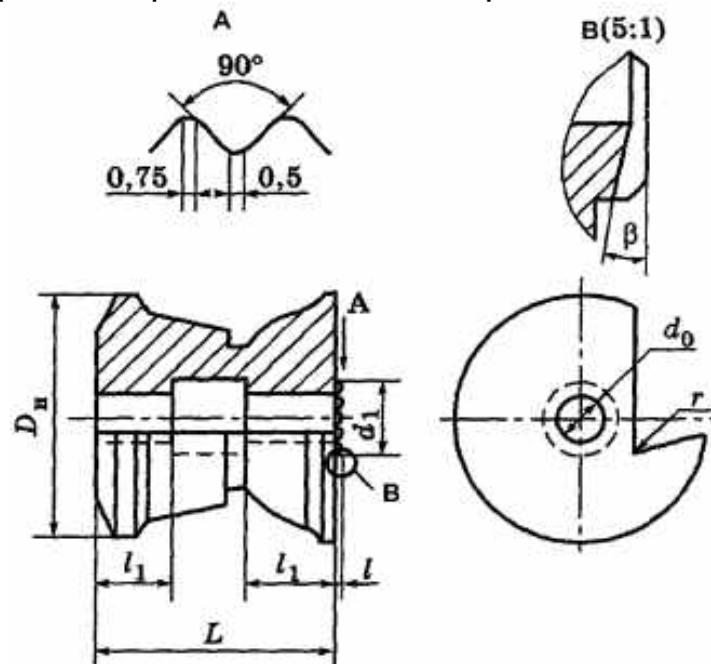


Figure 7 – Structural dimensions of circular form tool

Table 3 – Dimensions of serrated circular form tool for external work (see Figure 6, a) (mm)

Part form profile depth t_{max}	Form tool dimensions				Toothing dimensions	
	$D h8$	$d_0 H7$	r	l_1	d_1	l
up to 4	30	10	1	12	–	–
6	40-50	16	1	12	20	3
8	50-70	16	1	12	26	3
10	60-80	22	2	16	32	3
12	70-90	22	2	16	35	4
15	80-100	22	2	16	40	4
18	90-110	27	2	18	45	5
21	100-120	27	2	18	50	5

Notes: 1. For internal work $2R_{H max} = D_H = 2(0,65...0,75)r_{min}$, where r_{min} – minimal radius of work hole.

2. Neck's depth l_2 for screw head is $(0,25...0,5)L$.

3. For form tool with $\gamma < 15^\circ$ $v = 80^\circ$, and for form tool with $\gamma \geq 15^\circ$ $v = 70^\circ$.

Table 4 – Dimensions of circular form tool with six pin bores (Figure 6, b) (mm)

Part form profile depth t_{max}	Form tool dimensions						Bores dimensions	
	$D h8$	$d_0 H7$	d_1	b_{max}	k	r	D_1	d_2
6	50	13	20	9	3	1	28	5
8	60	16	25	11		2	34	
11	75	22	34	15	42			
14	90			18	45	6		
18	105	27	40	23	52		8	
25	125			30	55			

Table 5 – Dimensions of circular form tool with six pin bores (Fig 6, c) (mm)

Part form profile depth t_{max}	Type	Form tool dimensions								Bore dimensions				
		L	$D h8$	$d_0 H7$	d_1	d_2	f	l	k	d_4	$d_3 H10$	R	c	m
up to 6	I	up to 6	48	10	15	variable	2,5	6	9	–	4,1	9	8	–
	II	above 6						–		–				
up to 8	I	up to 10	52	12	19	32	4	10	10	–	6,2	11	10	–
		10...20						–		–				
	II	above 20						–		29				8
up to 11	I	up to 10	68	16	23	42	4	10	10	–	8,2	14	13	–
		10...20						–		–				
	III	above 20						–		37				8

Note. For form tool with $\gamma < 15^\circ$ $v = 80^\circ$, and for form tool with $\gamma \geq 15^\circ$ $v = 70^\circ$.

On the right side of the tool collar with corrugations is made for transmitting torque and rotation of the tool by $1/z$ after regrinding and placing its top on the distance h_p (Figure 11) from the horizontal axis of cutting tool. If the layer removed by regrinding is not compliant with the rotation on one corrugation, cutter gets an extra turn with the adjusting screw of the holder [4]. Number of corrugations teeth $z = 32 \dots 34$. The profile angle in their normal section is 90° . For a constant area length at the top of the teeth bottom of the

teeth space is disposed to the end of the collar at an angle β : $\text{tg}\beta = \pi/z$ (see Figure 7). The details on the end corrugations teeth are given in [5].

To simplify the production of circular form tool, its ends are made flat, but from the holder site (see Figure 6, b, c) one or more holes for a cylindrical pin, belonging to the toothed sector, are drilled.

Prismatic tools for locating and fixing have shank kind of "dovetail", and for height adjustment may have screw from reference end. Overall and mounting dimensions of flat form tools (Figure 8) are given in Table 6.

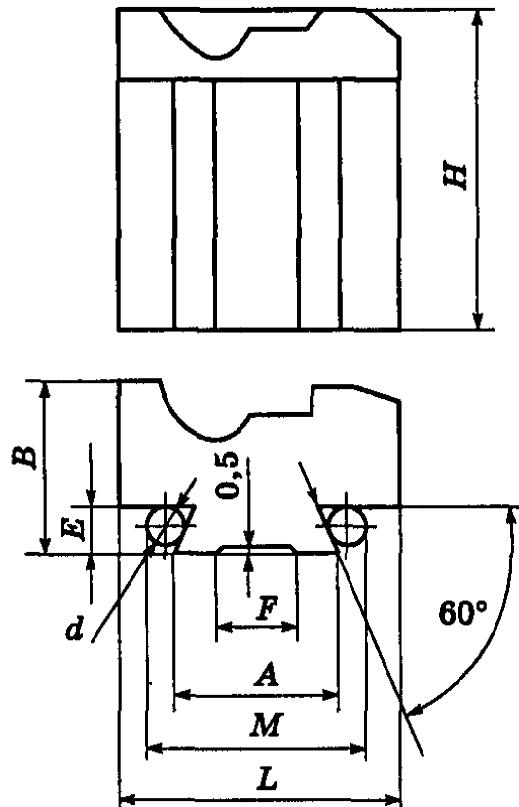


Figure 8 – Overall and mounting dimensions of flat form tool

Table 6 – Dimensions of flat form tool

Part form profile depth t_{max}	Form tool dimensions						Dimension M for rollers diameter d			
	B	H	$E_{0.03}$	A	F	r	$d_{\pm 0,005}$	$M_{\pm 0,05}$	$d_{\pm 0,005}$	$M_{\pm 0,05}$
up to 4	13	75	4	15	7	0,5	3	18,577	4	21,31
6	20		6	20	10		4	24,000	6	29,46
10	25			25	15		29,000	34,46		
14	35	90	10	30	20	1	6	34,846	10	45,77
20	45			40	25			44,846		55,77
28	60			60	40			64,536		83,66

The profile length of the form tool is determined depending on the size of the part profile with the additional blades and is rounded up in accordance with the normal row of standard sizes according to the GOST 6636-69.

With a width L , exceeding $2.5A$, application of larger sized shanks according to Table 6 is allowable.

In the absence of rollers with the diameters d , the table gives, available rollers are used, and the size M is calculated with the following formula:

$$M = A + d(1 + \text{ctg } \lambda/2) - 2E \cdot \text{ctg } \lambda,$$

where $\lambda = 60^\circ$ (Figure 8) [4].

Determination of the shape and profile sizes of flat form tool working part

Let formed part contour is set by nodal points 1, 2, 3, 4, and one of intermediate points - 5, and the axial distances between them l_1, l_2, l_3, l_4 , and radii r_1, r_2, r_3, r_4 are set by drawing (Figure 9). Based on properties of the processed material of the workpiece, design value of the rake angle γ (see Table 1), and draw from point 1 track of the front surface at this angle which will intersect the workpiece profile at points 1, 2/3, 4 and 5.

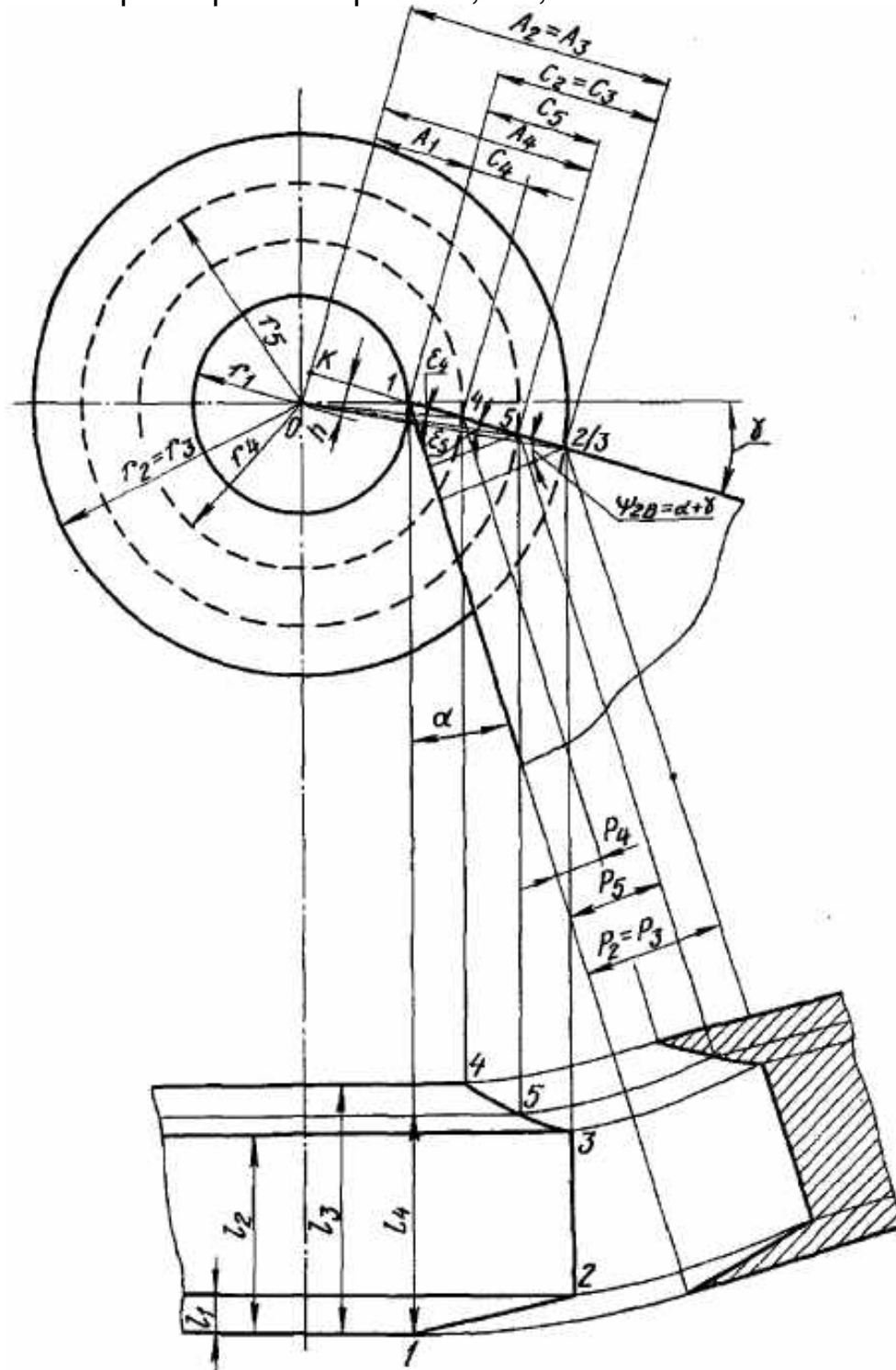


Figure 9 – Correctional calculation schema for flat form tool

Let's take for arbitrary coordinate axis straight line passing through the first nodal point 1 (typically the first number indicates the point corresponding to the smallest radius of the part r_1) at angle α to the cutting plane at this point. Then goal of correction calculations will be the calculation of the distance from the rectilinear generator point 1 to parallel to it rectilinear generators of the tool rear surface conducted through the nodal points 2/3, 4 and 5, i.e., determining sizes of $P_{2/3}$, P_4 and P_5 . To do this, perform some additional constructions. Let's lengthen track of front surface of the tool beyond point 1 to the left and drop perpendicular OK on it from the center of the workpiece O . Besides, connect the center O with points 1, 2/3, 4 and 5. From these points draw lines parallel to the segment OK . Distances from these lines to the segment OK let's denote by the letter A with the corresponding index of each nodal point. Thereafter from the points 2/3, 4 and 5, drop the perpendiculars to the rear surface of the tool, thereby obtain a series of rectangular triangles.

From the triangle 1 2/3 A , we have $R_2 = C_{2/3} \cos(\alpha + \gamma)$, where $C_{2/3} = A_2 - A_1$.

From the triangle 2/3 KO leg $A_2 = r_2 \cos \varepsilon_2$, and the angle $\varepsilon_2 = \arcsin (h/r_2)$, where $h = OK$.

The values of h and A_1 are determined from the triangle $OK1$:

$$h = r_1 \sin \gamma; A_1 = r_1 \cos \gamma.$$

In exactly the same way you can determine the value of P_4 and P_5 and the other for remaining points on the form tool profile.

In general, all the calculation formulas can be written as:

$$\begin{aligned} P_n &= C_n \cos (\alpha + \gamma); \\ C_n &= A_n - A_1; \\ A_n &= r_n \cos \varepsilon_n; \\ \varepsilon_n &= \arcsin (h/r_n). \end{aligned}$$

When $\lambda = 0$ axial dimensions of the work piece l_1, l_2, l_3, l_4 , are not distorted, i.e., they are equal to the distance between nodal points of the form tool profile.

Thus, make a construction of the cutting tool normal profile by the sizes of the work piece drawing and found values of $P_{2/3}, P_4$ and $P_5 \dots, P_n$.

Determination of the shape and sizes of the profile of the circular form tool working part

Similar to the correctional calculation of the flat form tool, circular form tool calculation is made. It is necessary to process the same formed part, for which the correctional calculation of the profile of the flat form tool was made.

Figure 11 shows a diagram of the correctional calculation of the circular form tool. The problem reduces to finding tool radii R_1, R_2, \dots, R_n , corresponding to the nodal points of the workpiece. In this case the radius of the most exposed point or outer diameter of the cutting tool is determined from tables ($R_1 = D_H/2$ (see Tables 3 – 5)) or by graphical method.

Prof. G. I. Granovsky [6] recommends graphical method for determining the diameter of the circular form tool, the essence of which is in following. From the center of an item O we draw two concentric circles of radius equal to the largest r and the smallest r_1 radii of the workpiece (Figure 10).

Through the point A draws two lines AM and AN at angles α and γ to the line joining this point with the center of the workpiece. At distance $l = 3 \dots 12$ mm from the point B pass the line perpendicular to the line OO . From point C bisect of the resulting angle ε . The intersection of this bisector with the line will give the desired point O_1 - the center of the form tool. Graphically found diameter of the tool is rounded to the nearest standard value (30, 40, 50, 60, 70, 80, 90, 100 mm).

The above method of determining the outer diameter of the tool is very simple and gives satisfactory results.

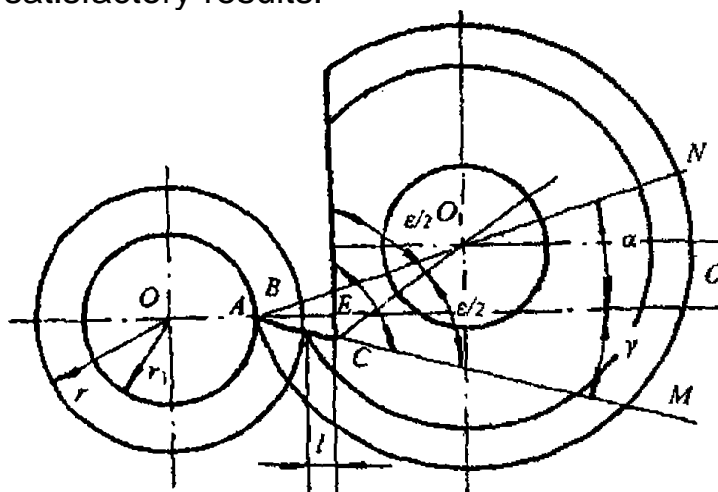


Figure 10 – Graphical method of circular form tool's overall sizes determination

Assume that the point 1 is located at a horizontal workpiece axis (Figure 11). Taking into account the value of relief angle α , adopted according to the tables ($\alpha = 8 \dots 12^\circ$), we displace tool's center O_p on the value

$$h_p = R_1 \sin \alpha$$

with respect to the workpiece center O .

From point 1 at an angle γ relatively to the horizontal axis of the workpiece, draw the trace of the tool front surface $1M$ and join tool center O_p with the nodal points 1, 2/3, 4 ... n , which lie at the intersection of the front surface trace with the workpiece circles with radii r_1, r_2, \dots, r_n . We obtained a number of right-angled triangles, $O_p1M, O_p2/3M, \dots, O_pnM$, with the common leg $O_pM = H_p$.

Making additional constructions exactly the same as for a flat form tool we obtain values A and C with the respective indices, and the distances B of nodes of the front surface 1, 4, 5, 2/3 to the center of the workpiece and to the point 1.

From the triangle $O_p M2/3$, we obtain: $R_{2/3} = \frac{H_p}{\sin \psi_2} = \frac{B_2}{\cos \psi_2}$.

And from triangle $O_p 1M$ we get: $H_p = R_1 \sin \psi_1$, $B_1 = R_1 \cos \psi_1$, where $\psi_1 = (\alpha + \gamma)$.

Leg B_2 of the triangle $O_p M2/3$ is determined by the construction: $B_2 = B_1 - C_2$ and the angle $\psi_2 = \arctg \frac{H_p}{B_2}$. Distance $C_2 = A_2 - A_1$, where $A_2 = r_2 \cos \varepsilon_2$, $A_1 =$

$= r_1 \cos \gamma$; $\varepsilon_2 = \arcsin \frac{r_1 \cdot \sin \gamma}{r_2}$.

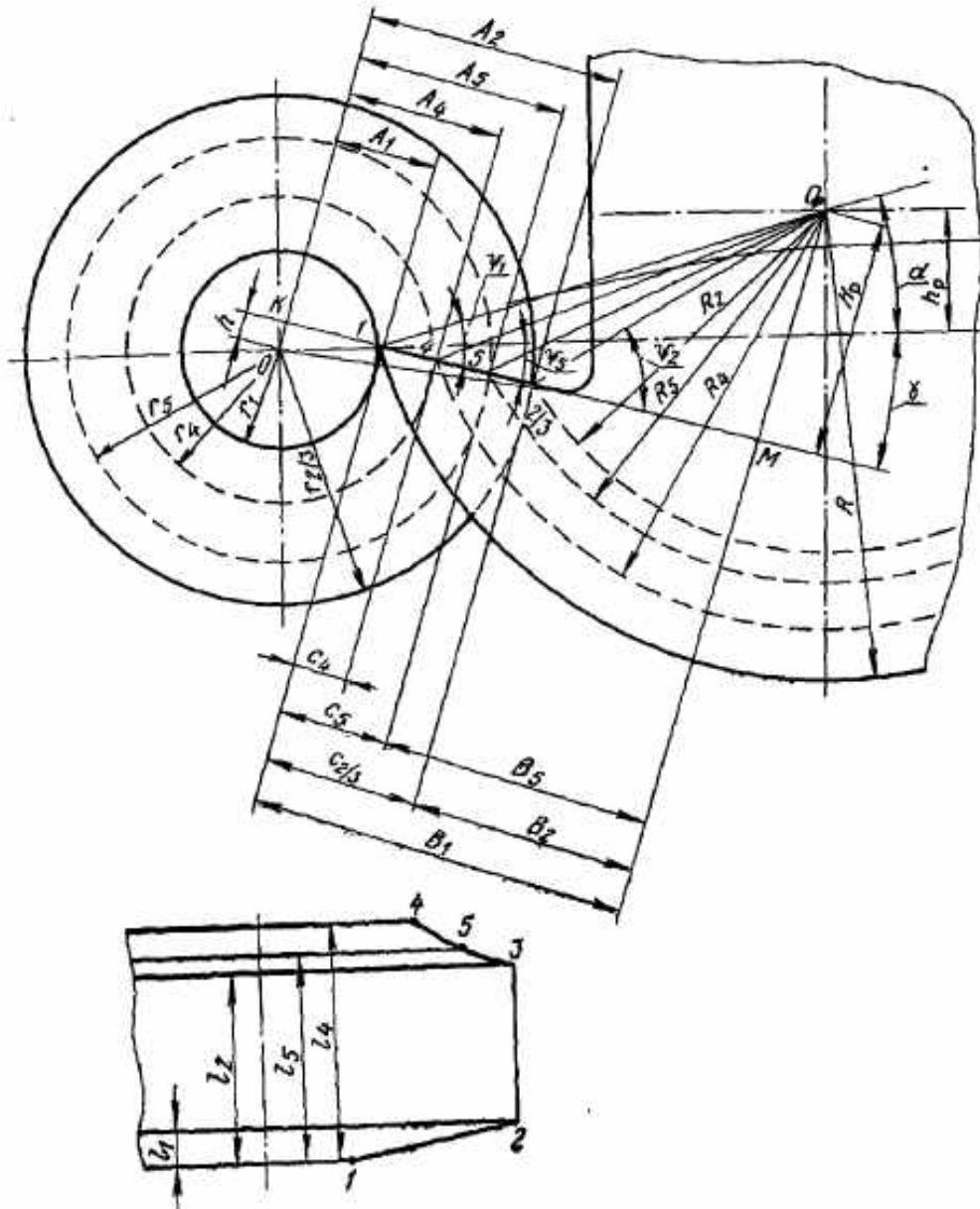


Figure 11 – Correctional calculation schema for circular form tool

In a similar way we define all the required tool radii R_1, R_2, \dots, R_n . In general, all the calculation formulas can be written as:

$$\psi_1 = (\alpha + \gamma);$$

$$\begin{aligned}
A_1 &= r_1 \cos \gamma; \\
\varepsilon_n &= \arcsin \frac{r_1 \cdot \sin \gamma}{r_n}; \\
A_n &= r_n \cos \varepsilon_n; \\
C_n &= A_n - A_1; \\
B_1 &= R_1 \cos \psi_1; \\
B_n &= B_1 - C_n; \\
H_p &= R_1 \sin \psi_1; \\
\psi_n &= \arctg \frac{H_p}{B_n}; \\
R_n &= \frac{H_p}{\sin \psi_n}.
\end{aligned}$$

These formulas are valid only if the axis of the tool and the workpiece are parallel. Under this condition, recalculation of tool axial dimensions is not made, because they are not distorted.

Graphic method of form tool profile determination

Graphic method of circular form tool profile determination is quite simple and visual. At the same time if the scale is chosen properly and the drawing is performed thoroughly, the accuracy will be practically identical to the one of the analytical calculation.

In actual practice of tool design offices both analytical and graphic methods of form tool and other complex-shaped cutting tool calculations are carried out simultaneously and the agreement of the results of these calculations are considered to be reliable. The need for different methods of calculation follows from the fact that when checking the results of the calculation using the same method, in which it was made, the same mistake, that was made earlier, could repeat. But if both analytical and graphic methods of calculations are carried out, then mistakes will be unlikely to coincide. Moreover, in case of deviations of the results of both calculations, mistakes are easy to find. You only should make checks in areas where there are significant differences.

The scale for the graphic method of profile determination is defined from the formula $M = \Delta/\delta$, where Δ is an accuracy of plotting, that depends on the available designer's means of drawing and his/her skills; δ – 0,25 of the most precise diameter tolerance of the workpiece [7].

The obtained value M is round up to the next higher standard value of the scale according to GOST 2.302-68, i.e. 4:1; 5:1; 10:1; 20:1; 40:1; 50:1; 100:1.

Initial data for the graphic method of form tool profile plotting are: part geometry (according to the fabrication drawing), tool's diameter D and chosen geometric parameters α and γ .

1. At the beginning we should plot the two-view drawing of the part cross-section (profile) in the chosen scale. To perform this we should draw an axial line and lay off the respective sizes of the part profile and plot a complete profile in the lower left corner of the drawing (see Figure 12).

In elevational drawing we should draw a form tool in its ending point. For this purpose the form tool point is located on circumference of the smallest part diameter, at height of centre [8].

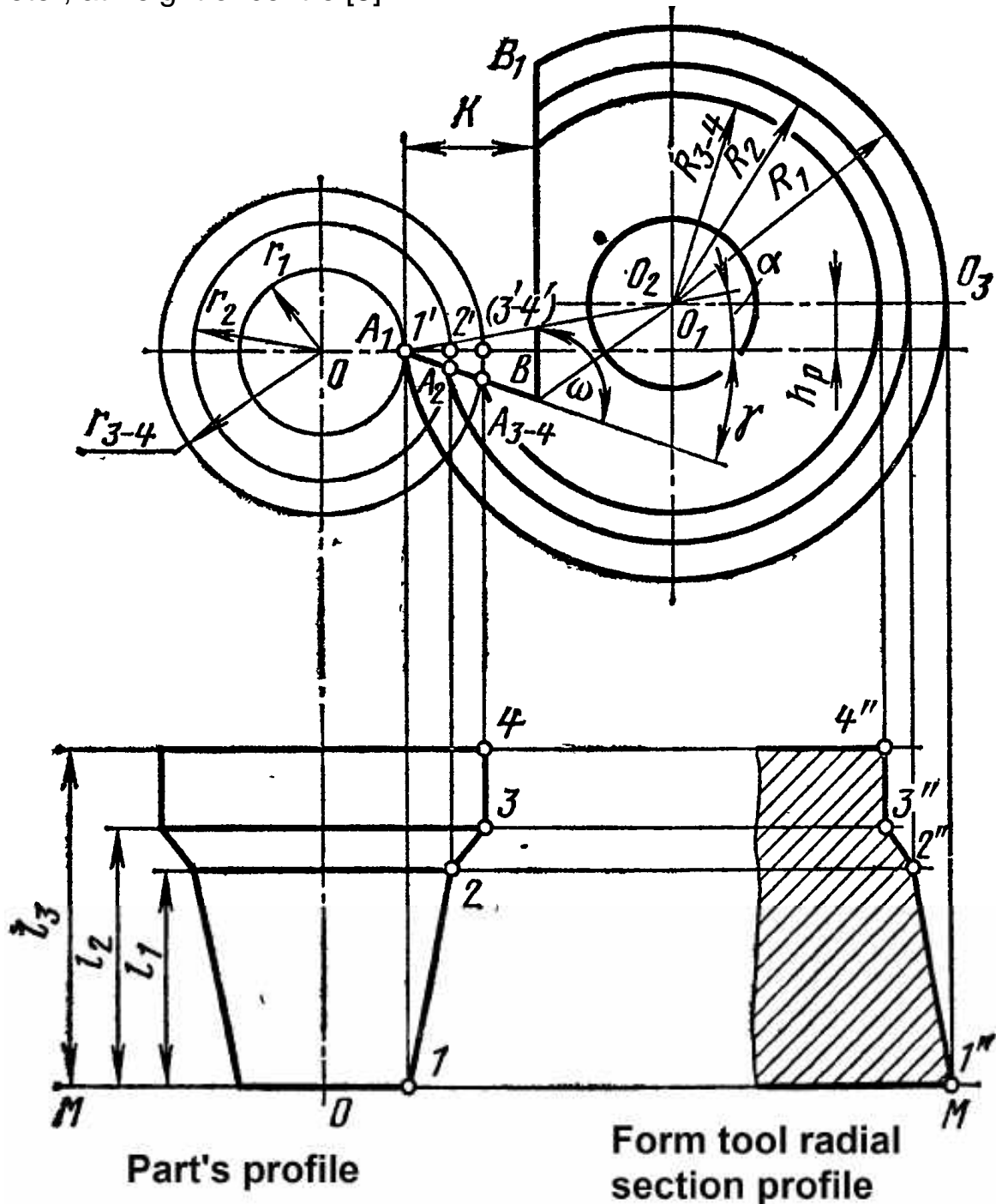


Figure 12 – Graphic plotting of the external circle form tool profile

2. The received points 1, 2, 3, 4 of the profile should be projected on the **OO** axis to receive 1', 2', 3', 4' points.

3. Out of the centre **O** circles of the respective radiuses r_1, r_2, r_3, r_4 should be drawn and as a result the part projection on the plane, that is perpendicular to the part axes, will be received.

4. The outer diameter should be specified. Out of the centre **O** of the part we should draw two circles of the biggest r_4 and the smallest r_1 radiuses of the part. The line (track) of the cutter face should be drawn to pass through the point 1' at the angle γ to the **OO** axis. The same way the line from the point 1' should be drawn at an angle α .

5. At distance of **K** from the point 1' line **BB₁** should be drawn perpendicularly to line **OO₁**. Distance **K** is a minimal distance required for the chip handling out of the cutter face. This distance is typically 3...10 mm bigger than the maximum part form profile depth t_{max} . From the point **B**, where line **BB₁** cross the cutter face, the line should be drawn to bisect angle ω . Point of intersection of this line and the one that drawn at the angle α is a desired point **O₂** – centre of the circle form tool, that will allow us to define its diameter.

6. Nominal diameter, overall and structural dimensions of the form tool should be defined. To find the centre of the circle form tool the other method could be applied: the spread of pair of compasses, that is equal to the radius of the outer circumference of the cutter, we should draw a mark out of the **A₁** point, that is on the intersection of the horizontal axis **OO₁** and the circle with radius r_1 . Then we should draw the line **O₂O₃**, which is parallel to the line **OO₁** at distance $h_p = R_1 \cdot \sin \alpha$; point **O₂** of intersection of this line with the mark will be a desired centre of the circle form tool.

7. On the line **A₁B** (track of the cutter face) we should mark points **A₁, A₂, A₃**, that we get as a result of it's intersection with respective radiuses of part surface circles.

8. By joining points **A₁, A₂, A₃** with the centre of the circle form tool **O₂**, we will get respective radiuses of the cutter **R₁, R₂, R₃**.

9. The circle form tool radial section should be drawn: a) draw line **MM**; b) draw lines, parallel to **MM** at the distance l_1, l_2, l_3 , that corresponds to the axial sizes of the part; c) by projecting the points of intersection of circles with radiuses **R₁, R₂, R₃** and the line **O₂O₃**, that passes through the cutter's centre, on the line, that is parallel to **MM** line, we will get the form tool radial section (points 1'', 2'', 3'', 4'').

10. To plot the profile gage and counterpart for form tool profile control we should evaluate the difference of all node points radiuses relative to the contour node point 1'': $P_2 = R_1 - R_2$ etc.

11. The working drawing of the cutter should be done. If the tool rake $\gamma=0$, then circular form tool profile should be plotted in the same order but the line A_1B coincide with the line OO_1 .

If the part has an intricate curvilinear profile then it is recommended to cut it by parallel lines, that are perpendicular to the part axis and passes at the equal distance from each other. For each section radius of specified node point r should be specified graphically [3].

Replacement of profile graphs of form tools and mills by arcs of circles with conjugated straight lines

Profiles of formed parts, which usually consist of various combinations of the straight and arc sections, differ from profiles of form tools and mills not only by height, but for certain types and by width of the tool. Coordinates of passing points are also different in view of presence rake and relief angles in the instrument.

Arc sections of the parts profile meet the tool curves, which are usually replaced by arcs of circles. Arc sections on the tool profile, built on the found by the calculation extreme and nodal points, are different from the arc sections of the parts profile in the size range, and often also by the coordinates of the center and junction points with the straight sections. Profile angle values are changed on the straight sections.

The following formulas to calculate angle and arc sections of the tool profile are given for the most frequently used typical profiles of the cutting tools and especially form milling cutters. The calculation is carried out after the height and width of the nodal and extreme points of the tool profile are found and you need only specify the size of angles, radii and the coordinates of their centers on the profile of the tool.

Replacement the tool profile by arcs of circles and straight lines introduces distortion in the tool profile. Therefore tool profiles, designated for precision machining, are given by their coordinates of points with small intervals.

The following are calculation methods for the number of typical profiles, consisting of combination of straight lines and circular arcs.

1. Typical profile 1 - angle (Figure13, a).

Known quantities of the tool profile: x - width; h - height of the profile.

The angle β is defined by formula: $\text{tg } \beta = x/h$.

2. Typical profile 2 – arc, not symmetrical within $\frac{1}{4}$ of the circle or symmetric within $\frac{1}{2}$ of the circle (Figure13, b).

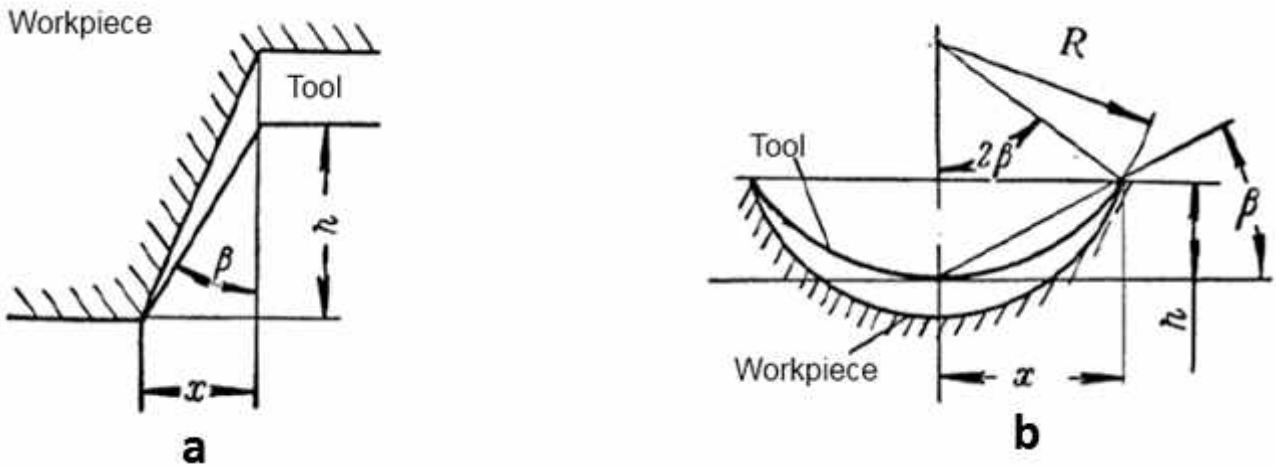


Figure 13 – Typical profiles
 a – profile №1 – angle; b – profile №2 – arc

Given values of the profile: x - width of the arc profile; h - height of the profile.

The radius R of the arc profile is defined by formulas:

$$\begin{aligned} \operatorname{tg} \beta &= h/x; \\ R &= x/\sin 2\beta, \end{aligned}$$

where β - intermediate calculated value.

3. Typical profile 3 - arc, not symmetrical within $\frac{1}{2}$ of the circle (Figure 14).

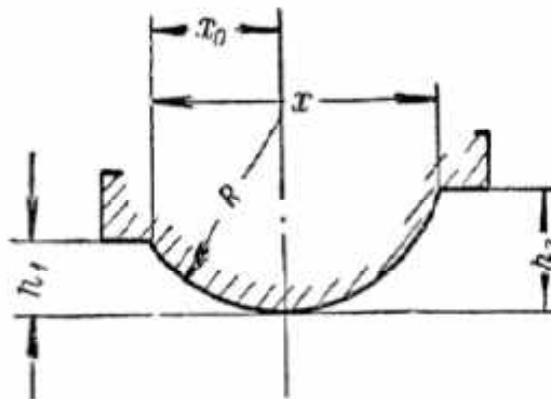


Figure 14 – Typical profile №3 – arch, irregular

Known quantities of the tool profile: x - width between extremities of the profile; h_1 - lower height of the extreme point of the profile and h_2 - bigger height of the extreme point of the profile.

The radius of the arc profile and the abscissa x_0 of the circle center to the extreme point with lower height is determined by formulas:

$$\begin{aligned} \operatorname{tg} \beta &= (h_2 - h_1)/x; \\ A &= 2\sqrt{h_1 \cdot h_2} \cos \beta; \end{aligned}$$

$$R = \frac{h_1 + h_2 - A}{2 \sin^2 \beta};$$

$$x_0 = \sqrt{h_1(2R - h_1)},$$

where A and β - intermediate calculated values.

The abscissa value x_0 on the tool does not match with the corresponding coordinate value on the workpiece profile.

4. Typical profile №4a - arc with one conjugated straight line (Figure 15,a).
Given values of the tool profile: h, h_1, h_2 - heights; x and x_0 - abscissas.

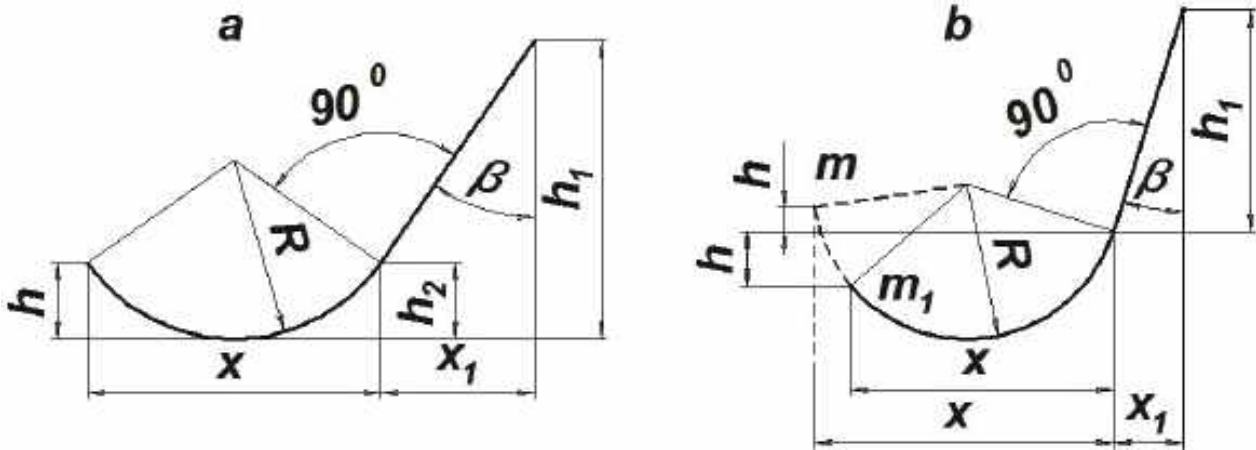


Figure 15 – Typical profile №4 – arc with one conjugated straight line

Angle β of the straight section and the radius R of the arc section of the profile is defined by the following formulas:

$$\operatorname{tg} \beta = \frac{x_1}{h_1 - h_2};$$

$$y = \sqrt{2xh \cdot \cos \beta - x^2 \sin^2 \beta};$$

$$R = \frac{x \cos \beta + h - y}{\cos^2 \beta},$$

For the case when the profile line is perpendicular to the baseline, i.e., $x_1 = 0$ and $\beta = 0$, respectively, the radius of the arc section is defined by the formula:

$$R = x + h - \sqrt{2xh}.$$

5. Typical profile 4b - arc with one conjugated straight line (Figure 13,b).
Known quantities of the tool profile: h, h_1 - heights; x and x_1 - abscissas.

Angle β of the straight section and the radius R of the arc section is defined by the formulas:

$$\operatorname{tg} \beta = x_1/h_1;$$

$$\operatorname{tg} \delta = h/x;$$

$$R = \frac{x}{2} \operatorname{sec} \delta \cdot \sec(\beta \mp \delta),$$

where angle δ - intermediate calculated value.

The minus sign in the third formula corresponds to the case of counting h from point m . The plus sign corresponds to the case of counting h from point m_1 . In the case of $x_1 = 0$ and $\beta = 0$, i.e. when the profile line is perpendicular to the base line, the radius $R = \frac{x}{2} \sec^2 \delta$. If heights h , and h_1 , on the drawing are defined from the lowest point of the arc, than R and β are defined by the formulas for typical profile 4a.

6. Typical profile 5 - arc with two conjugated lines (Figure 16).

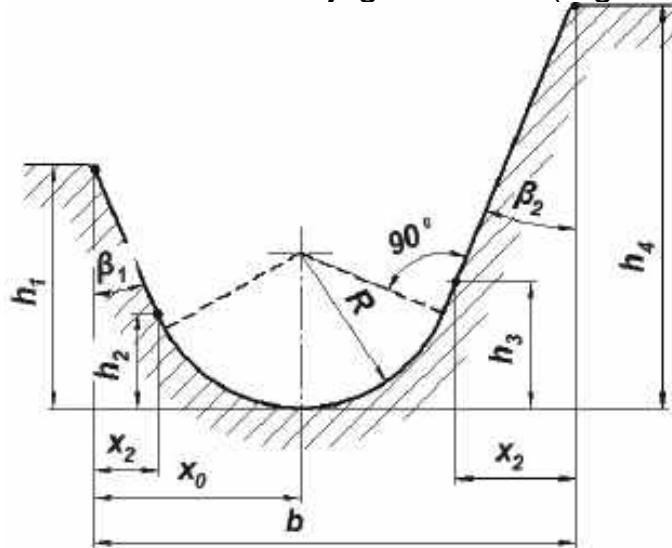


Figure 16 – Typical profile №5 – arc with two conjugated lines ($h_{1\theta} > R_\theta$)

The following formula is recommended for the case when height of extreme points of the workpiece profile h_θ^* is larger than the radius R_θ i.e.

$$h_{1\theta} > R_\theta \text{ and } h_{4\theta} > R_\theta.$$

Known values: h_1, h_2, h_3, h_4 - heights of the tool profile; x_1, x_2 - abscissas; b - width of the tool profile.

Angles β_1 and β_2 of straight sections, the radius R of the arc section, and the abscissa of the center x_0 are determined by the formulas:

$$\operatorname{tg} \beta_1 = \frac{x_1}{h_1 - h_2};$$

$$\operatorname{tg} \beta_2 = \frac{x_2}{h_4 - h_3};$$

$$B = b - h_1 \operatorname{tg} \beta_1 - h_4 \operatorname{tg} \beta_2;$$

$$C = \operatorname{tg} \frac{90^\circ - \beta_1}{2} + \operatorname{tg} \frac{90^\circ - \beta_2}{2};$$

$$R = B/C;$$

$$D = (h_1 - R) \operatorname{tg} \beta_1;$$

$$E = R \sec \beta_1;$$

$$x_0 = D + E,$$

where B, C, D and E - the intermediate calculated values.

The abscissas x_1 and x_2 of the junction points of straight sections with arc workpiece profile do not coincide with the abscissas of the junction points of the replacing tool profile. According to the given formulas replacement of the straight sections on the tool profile is performed more accurately than replacement of the arc section. The abscissa value x_0 on the tool does not coincide with the corresponding abscissa on the workpiece profile.

7. Typical profile 6 - arc with two conjugated lines (Figure17). The following formula is recommended for the case when the height of extreme points of the workpiece profile h_0 is smaller than the radius R_0 of the workpiece profile, i.e.

$$h_{10} < R_0 \text{ and } h_{40} < R_0.$$

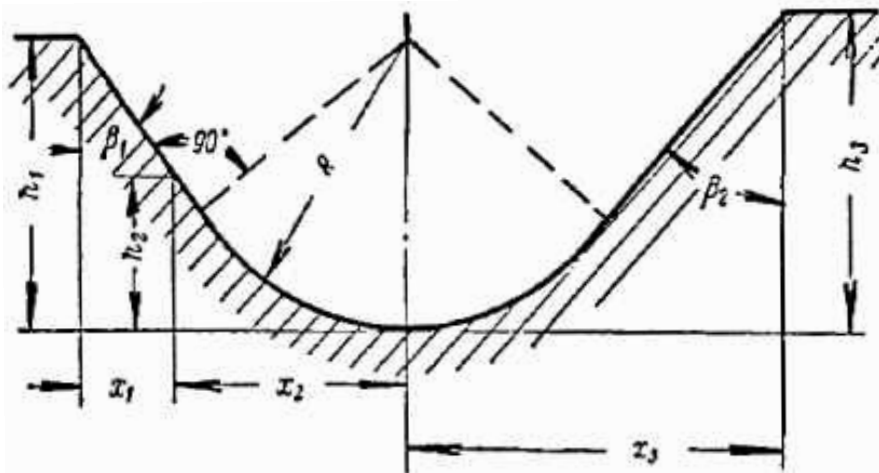


Figure 17 – Typical profile №6 – arc with two conjugated lines ($h_{10} < R_0$)

Known quantities of the tool profile: x_1 , x_2 , x_3 - abscissas; h_1 , h_2 , h_3 , - heights.

Angles β_1 and β_2 , and the radius R are defined by the following formulas:

$$\text{tg } \delta = h_2/x_2;$$

$$R = x_2/\sin 2\delta;$$

$$\text{tg } \lambda_1 = \frac{R - h_1}{x_1 + x_2};$$

$$\cos \varphi_1 = \frac{R \cos \lambda_1}{x_1 + x_2};$$

$$\beta_1 = \varphi_1 + \lambda_1;$$

$$\text{tg } \lambda_2 = \frac{R - h_3}{x_3};$$

$$\cos \varphi_2 = \frac{R \cdot \cos \lambda_2}{x_3};$$

$$\beta_2 = \varphi_2 + \lambda_2,$$

where δ , λ_1 , φ_1 , λ_2 , φ_2 - intermediate calculated values.

Abscissas of junction points of the workpiece profile do not match with the abscissas of the junction points of the tool profile. According to the formulas replacement of the arc section with abscissa x_2 and straight with the angle β_1 is more accurate than the replacement of the remaining portion of the profile.

8. Typical profile 7 – with two conjugated circular arcs and two conjugated straight lines (Figure 18).

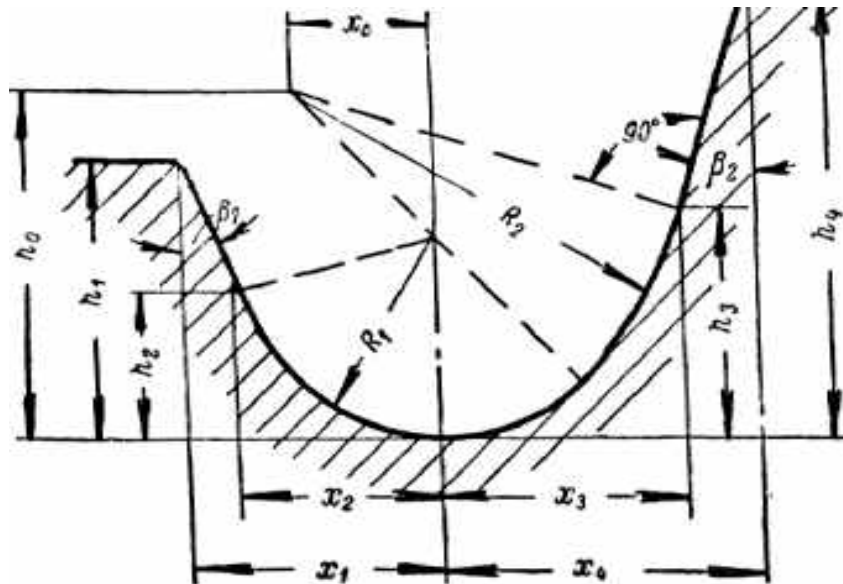


Figure 18 – Typical profile №7 – with two conjugated circular arcs and two conjugated straight lines

The given values of the tool profile: x_1, x_2, x_3, x_4 - abscissas; h_1, h_2, h_3, h_4 - heights.

$R_1, R_2, \beta_1, \beta_2, x_0, h_0$ are defined by the following formulas:

$$\operatorname{tg} \beta_1 = \frac{x_1 - x_2}{h_1 - h_2};$$

$$A = x_1 - h_1 \cdot \operatorname{tg} \beta_1;$$

$$R_1 = A \cdot \operatorname{tg} \frac{90^\circ + \beta_1}{2};$$

$$\operatorname{tg} \mu = \pm \frac{R_1 - h_3}{x_3};$$

$$K = x_3 \cdot \sec \mu;$$

$$\operatorname{tg} \beta_2 = \frac{x_4 - x_3}{h_4 - h_3};$$

$$B = K \cdot \cos(\beta_2 \mp \mu) - R_1;$$

$$R_2 = \frac{K^2 - R_1^2}{2B};$$

$$x_0 = R_2 \cdot \cos \beta_2 - x_3;$$

$$h_0 = R_2 \cdot \sin \beta_2 + h_3,$$

where A , μ , K and B - intermediate calculated values.

The upper sign in the formulas for μ and B is taken at $R_1 > h_3$, and the bottom at $R_1 < h_3$.

9. Typical profile 8 - with three conjugated circular arcs (Figure 19).

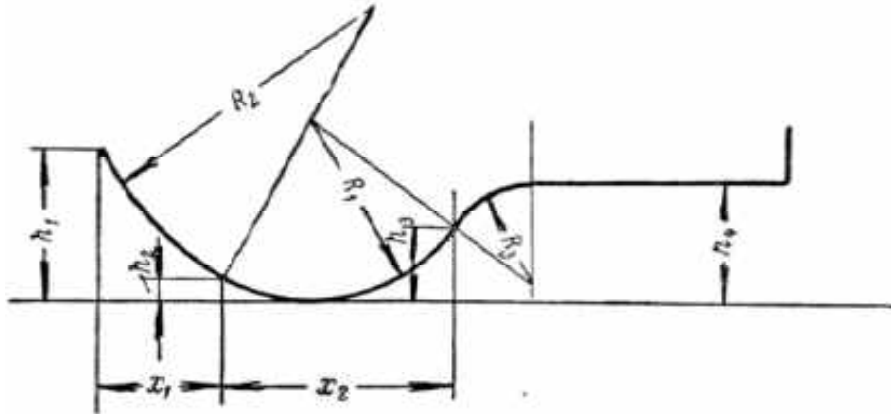


Figure 19 – Typical profile №8 – with three conjugated circular arcs

The given values of the tool profile: x_1 , x_2 - abscissas; h_1 , h_2 , h_3 , h_4 - heights.

R_1 , R_2 , R_3 - radii of arc sections - are determined by the formulas:

$$\operatorname{tg} \beta = (h_3 - h_2)/x_2;$$

$$A = 2\sqrt{h_2 \cdot h_3 \cos \beta};$$

$$R_1 = \frac{h_2 + h_3 - A}{2\sin^2 \beta};$$

$$\sin \lambda = \frac{R_1 - h_2}{R_1};$$

$$\operatorname{tg} \mu = \frac{h_1 - h_2}{x_1};$$

$$\delta = 180^\circ - (\lambda + \mu);$$

$$R_2 = \frac{x_1}{2} \sec \mu \cdot \sec \delta;$$

$$\sin \varepsilon = \frac{R_1 - h_3}{R_1};$$

$$R_3 = \frac{h_4 - h_3}{1 - \sin \varepsilon},$$

where β , A , μ , λ , δ - intermediate calculated values.

10. Typical profile 9 - with four arc sections and two non-conjugated lines (Figure 20).

The given values of the tool profile: x_1 , x_2 , x_3 , x_4 , x_5 , x_6 - abscissas; h_1 , h_2 , h_3 , h_4 , h_5 , h_6 - heights.

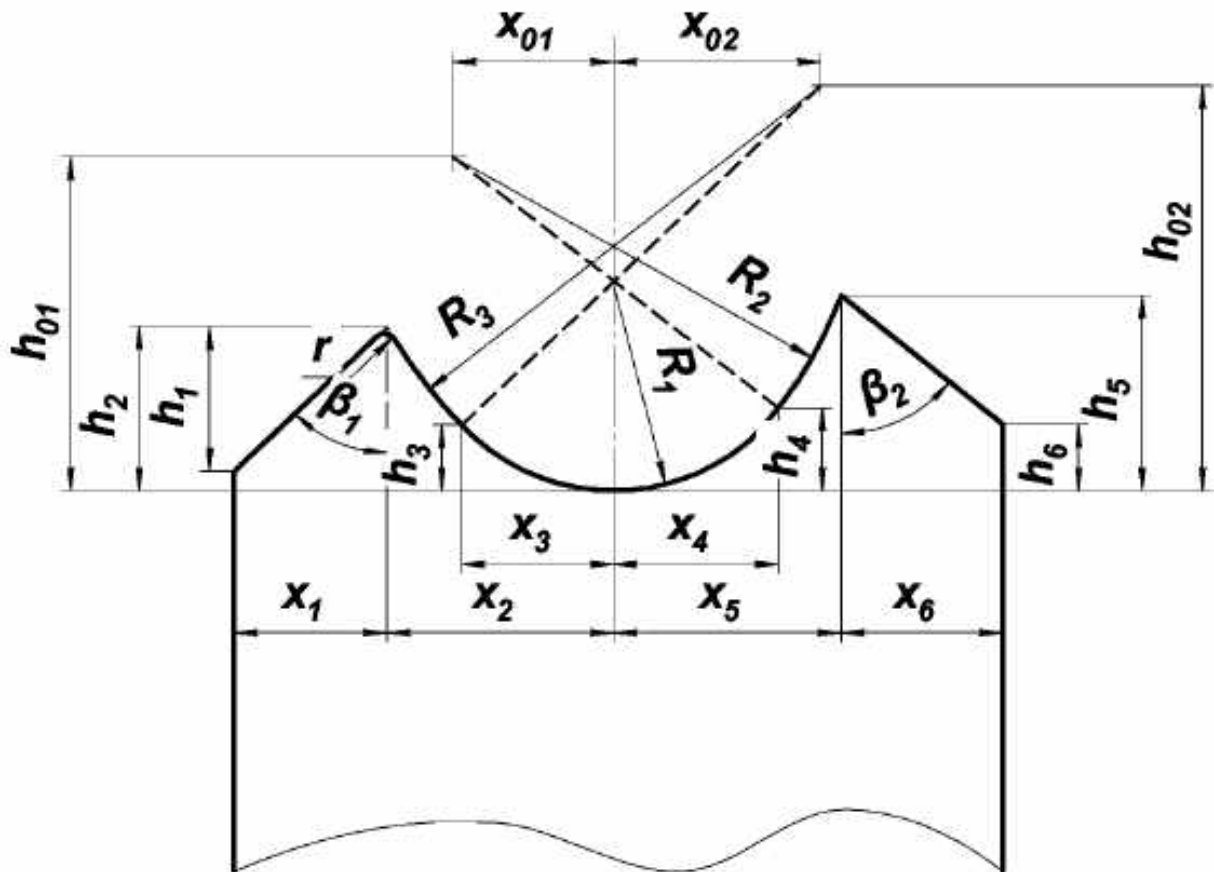


Figure 20 – Typical profile №9 - with four arc sections

The values of R_1 , R_2 , R_3 , x_{01} , h_{01} , x_{02} , h_{02} , β_1 , β_2 , r - are determined by the formulas:

$$\begin{aligned} \operatorname{tg} \mu &= h_2/h_3; \\ R_1 &= x_3 \operatorname{cosec} 2\mu; \\ \operatorname{tg} \lambda &= \frac{h_2 - h_3}{x_2 - x_3}; \\ R_3 &= \frac{x_2 - x_3}{2} \operatorname{sec} \lambda \cdot \operatorname{cosec}(\lambda - 2\mu); \\ x_{02} &= R_3 \sin 2\mu - x_3; \\ h_{02} &= R_3 \cos 2\mu + h_3; \\ \sin \delta &= x_4/R_1; \\ \operatorname{tg} \lambda_1 &= \frac{h_5 - x_4 \operatorname{tg} \frac{\delta}{2}}{x_5 - x_4}; \\ R_2 &= \frac{x_5 - x_4}{2} \operatorname{sec} \lambda_1 \cdot \operatorname{cosec}(\lambda_1 - \delta); \\ x_{01} &= R_2 \sin \delta - x_4; \\ h_{01} &= R_2 \cos \delta - h_4; \\ \operatorname{tg} \beta_1 &= x_1/h_1; \\ \operatorname{tg} \beta_2 &= x_6/(h_5 - h_6), \end{aligned}$$

where μ , λ , δ and λ_1 - intermediate calculated values.

Coordinates of the circles centers of the arc sections of the tool profile do not coincide with the coordinates of the centers of the workpiece profile arcs. For small radius r it is transferred from the workpiece profile on the cutter profile unchanged [5].

Calculation of errors while machining by form tool

Form cutters, whose base point (one or more) of the cutting edge is located on the center line of workpiece, are most widely used in the production. When processing parts with conical or radius sections by such cutters the errors occur. This is due to the fact that because of the angle γ cutting edges of the tools processing these sections do not lie on the center line of workpiece. Theoretically, for elimination error on the conical or radius sections it is necessary to manufacture tool profile in section A-A by complicated curves of the second order. For example, the section of the form cutters profile 1_p-2_p should be made hyperbolic and the profile section $1_p-2_p-3_p$ should be a part of ellipse (Figure 21).

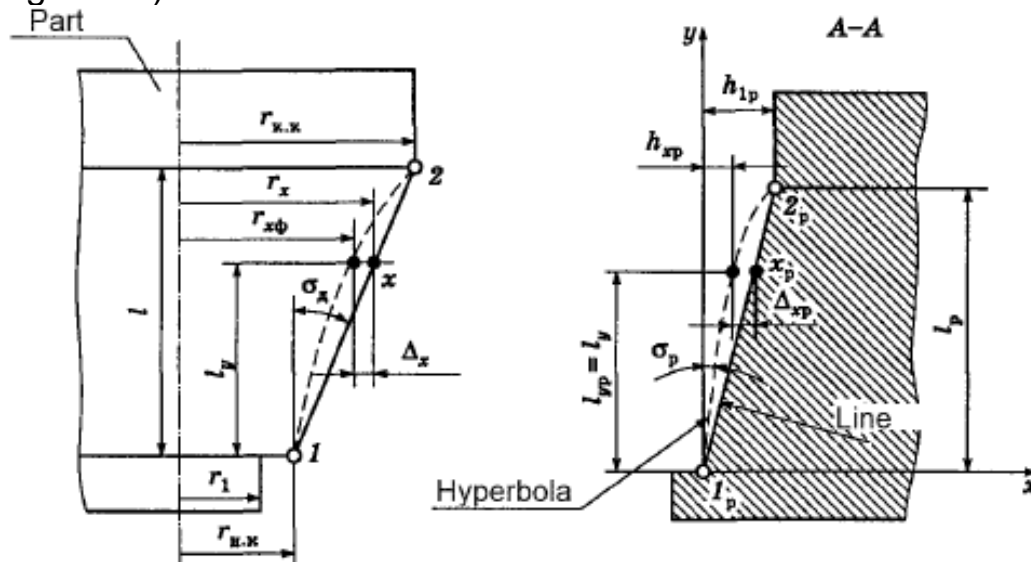


Figure 21 – Scheme for calculation of working error on the taper section of the part (section **A-A** is perpendicular to the tool back plane)

According to the above formulas of correction calculation we can calculate the height of the cutter characteristic points profile and then by their coordinates to determine the equations of these curves. However, the production of cutting tools with such a complex profile is connected with great difficulties. Therefore in practice profile section 1_p-2_p is manufactured in a straight line with an angle σ_p to facilitate the manufacture of profile cutters while in section $1_p-2_p-3_p$ – in arc of a circle of radius r_p with coordinates x_0 and y_0 . This leads to the formation of the error Δ_{xp} on the profile tool at the point x_p , which while processing is transferred to the workpiece and form the profile error Δ_x at the point x . In this case if the tool profile has the error to the convex side then on the details the error will be to the concave side and vice versa.

In Table 7 the formulas for calculating errors on a conical section of the workpiece while processing by flat and circular form tools are listed.

Table 7 – Sequence of error calculation on the taper section of the part

Flat form tool for external processing	Circular form tool for external processing	Circular form tool for internal processing
1) $\sin y_H = (r_1 \sin y) / r_{H,K}$;	1) $\sin y_H = (r_1 \sin y) / r_{H,K}$;	1) $\sin y_H = (r_1 \sin y) / r_{H,K}$;
2) $C_H = [r_{H,K} \sin(y - Y_H)] / \sin y$;	2) $C_H = [r_{H,K} \sin(y - Y_H)] / \sin y$;	2) $\sin y_K = (r_1 \sin y) / r_{K,K}$;
3) $h_H = C_H \cos(\alpha + Y)$;	3) $h_H = C_H \cos(\alpha + Y)$;	3) $C_H = [r_{H,K} \sin(y_H - Y)] / \sin y$;
4) $\sin y_K = (r_1 \sin y) / r_{K,K}$;	4) $\sin y_K = (r_1 \sin y) / r_{K,K}$;	4) $R_{H,K} = \sqrt{R_H^2 + C_K^2 - 2R_H C_K \cos(\alpha + Y)}$;
5) $C_K = [r_{K,K} \sin(y - Y_K)] / \sin y$;	5) $C_K = [r_{K,K} \sin(y - Y_K)] / \sin y$;	5) $C_K = [r_{K,K} \sin(y_K - Y)] / \sin y$;
6) $h_K = C_K \cos(\alpha + Y)$;	6) $R_{H,K} = \sqrt{R_H^2 + C_K^2 - 2R_H C_K \cos(\alpha + Y)}$;	6) $R_{K,K} = \sqrt{R_H^2 + C_K^2 - 2R_H C_K \cos(\alpha + Y)}$;
7) $\operatorname{tg} \sigma_p = (h_K - h_H) / l$;	7) $R_{K,K} = \sqrt{R_H^2 + C_K^2 - 2R_H C_K \cos(\alpha + Y)}$;	7) $h_{p,K} = R_{H,K} - R_{K,K}$;
8) $C_x = (l_y \operatorname{tg} \sigma_p) / \cos(\alpha + Y)$;	8) $h_{p,K} = R_{H,K} - R_{K,K}$;	8) $\operatorname{tg} \sigma_p = h_{p,K} / l$;
9) $A_x = C_x + r_1 \cos y$;	9) $\operatorname{tg} \sigma_p = h_{p,K} / l$;	9) $R_x = R_{K,K} - l_y \operatorname{tg} \sigma_p$;
10) $r_{\phi x} = \sqrt{A_x^2 + (r_1 \sin y)^2}$;	10) $R_x = R_{H,K} - l_y \operatorname{tg} \sigma_p$;	10) $C_x = R_H \cos(\alpha + Y) - \sqrt{R_x^2 - [R_H \sin(\alpha + Y)]^2}$;
11) $\operatorname{tg} \sigma_\theta = (h_{K,K} - h_{H,K}) / l$;	11) $C_x = R_H \cos(\alpha + Y) - \sqrt{R_x^2 - [R_H \sin(\alpha + Y)]^2}$;	11) $m = r_1 \sin y$;
12) $r_{TX} = r_1 + l_y \operatorname{tg} \sigma_\theta$;	12) $m = r_1 \sin y$;	12) $A_1 = r_1 \cos y$;
13) $\Delta_x = r_{\phi x} - r_{TX}$.	13) $B_x = r_1 \cos y$;	13) $B_x = A_1 - C_x$;
	14) $A_x = C_x + B_x$;	14) $r_{\phi x} = \sqrt{m^2 + B_x^2}$;
	15) $r_{\phi x} = \sqrt{m^2 + A_x^2}$;	15) $\operatorname{tg} \sigma_\theta = (h_{K,K} - h_{H,K}) / l$;
	16) $\operatorname{tg} \sigma_\theta = (h_{K,K} - h_{H,K}) / l$;	16) $r_{TX} = r_{H,K} + l_y \operatorname{tg} \sigma_\theta$;
	17) $r_{TX} = r_{H,K} + l_y \operatorname{tg} \sigma_\theta$;	17) $\Delta_x = r_{TX} - r_{\phi x}$.
	18) $\Delta_x = r_{TX} - r_{\phi x}$.	

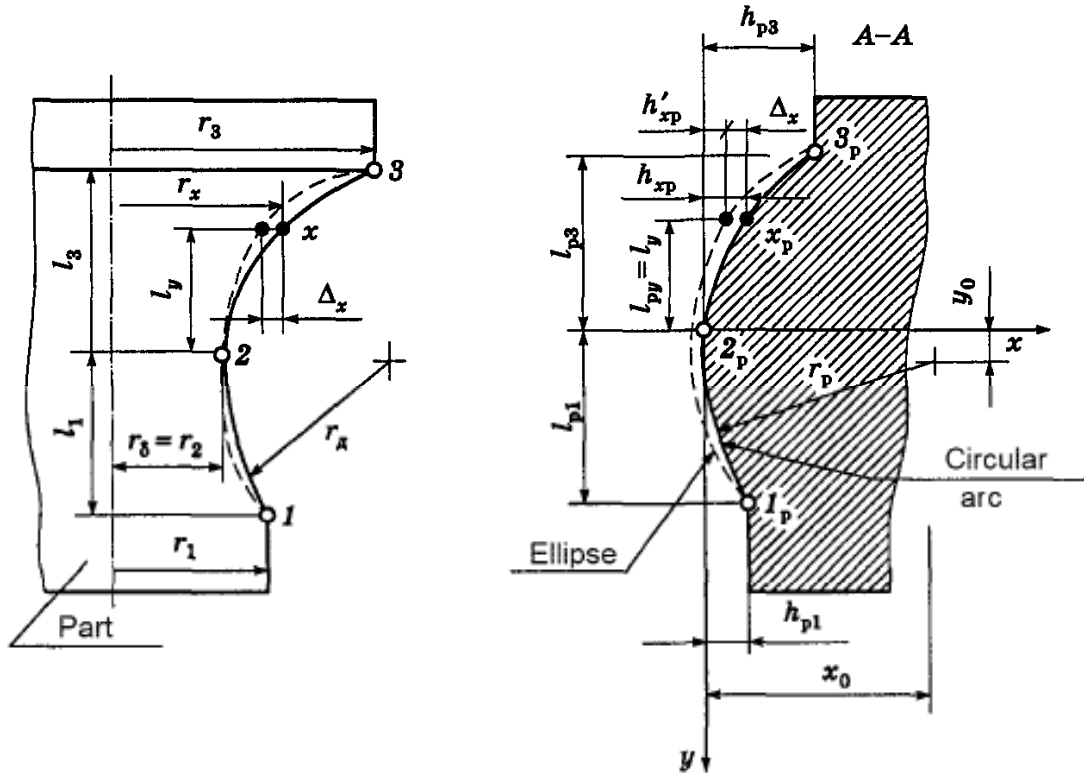


Figure 22 – Scheme for calculation of working error on the radius section of the part (section **A-A** is perpendicular to the tool back plane)

Calculation of the error at the point x of the workpiece with radius surface (Figure 22) after processing with form cutters is held in the following order:

- 1) by the coordinates of three points $1_p-2_p-3_p$ of the tool profile in the section **A-A** values of r_p , x_0 and y_0 are calculated;
- 2) point x is selected on the workpiece profile at a distance l_y from the base point 2 and the value of r_x is calculated using the formula

$$r_x = r_2 + r_3 - \sqrt{r_3^2 - l_y^2}.$$

Point x is recommended to choose from the longer section (section 2-3), and $l_{yp} = l_y = 0,4l_2 + \Delta l$ (in the first calculation $\Delta l = 0$, and in further ones it increases in increment of 0,2...0,4 mm);

- 3) by value r_x and cutter parameters the distance from the tool profile h'_{xp} to the base point 2 is determined;

- 4) value of h_{xp} is calculated for the point x_p , located on the section of the radius r_p cutter circle:

$$h_{xp} = x_0 - \sqrt{x_0^2 + 2y_0l_y - l_y^2}.$$

Error of the tool profile at the point x_p is equal to $\Delta_{xp} = h_{p1} - h'_{xp}$ and the sign of the error depends on the position of the point and the values of r_p , x_0 and y_0 . To determine the maximum error values of Δl must be set and it is necessary to perform calculations to obtain the maximum value of Δ_{xp} . The

error of the profile on the workpiece at the point x can be accepted $\Delta_x \approx \Delta_{xp}$. This will greatly simplify the further calculations and make error to 8%, which is sufficient for practice. While processing by conventional circular form tools, having one point on the workpiece axis, the error on the conical and radius workpiece surfaces is slightly larger than after processing by flat form tools [1].

To reduce the workpiece errors it is appropriate to reduce the angles γ and α in flat form tools and reduce the angles and increase the outer diameter in the circular form tools. Error at the conical sections of the workpiece can be reduced by applying form tools with angles γ and λ , so the cutting edge is located on the center line of items. After processing such construction by flat form tool the error at the conical section of the workpiece will be equal to zero, and after processing by the circular form tool it is reduced by 3-5 times compared to the error arising during processing by circular tool of conventional design. The maximum error on conical and radius surfaces of the workpieces after machining by form tools $\Delta_{max} < (0,5...0,6)T_1$, where T_1 - tolerance on the radius of the workpiece. If this condition is not met it is necessary to change the type or parameters of the form tool.

Calculation of the gauges to control form tool

Executive dimensions and tolerances largely determine the dimensional stability and service life of form tools. It is necessary to consider this when you calculate height and linear dimensions of form tools and gauges. When calculating high-level dimensions of gauges h_k it is necessary to divide them into female and male, since they have different working conditions and wear during the operation (Figure 23).

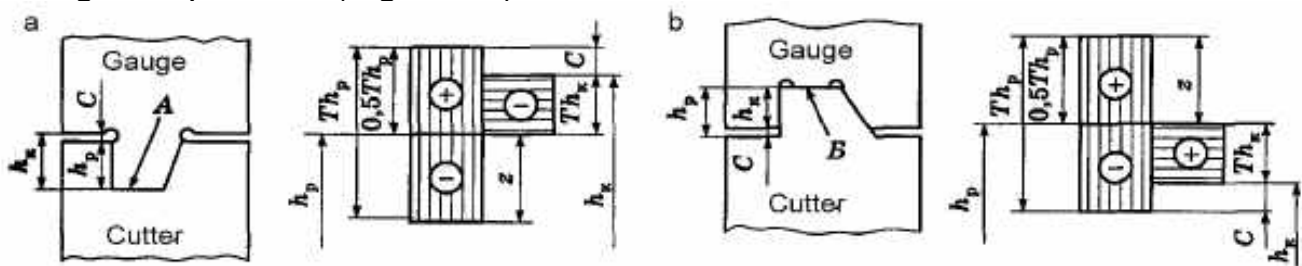


Figure 23 – Height dimensions and tolerance bands for the form tool and the gauge: a – the gauge is an internal member; b – the gauge is an external member

During the control of the tool profile by the male gauge its wear will occur on the surface A. In this case, the size h_k will decrease, so size of the gauge profile height should be appointed, focusing on the permissible maximum dimension of the tool profile height:

$$h_k = (h_p + 0,5Th_p - C)_{-Th_k},$$

where Th_p , Th_k - tolerances for the height of the tool and gauge, respectively;

$z = 0,5 Th_p$ - gauge wear tolerance (see Figure 23).

To compensate the "light clearance" it is necessary to leave some tolerance of the size C laying it down from the maximum size. During the control of the tool profile by the female gauge its wear will occur on the surface B . In this case the size h_k will increase, so size of the gauge profile height should be appointed focusing on the permissible minimum dimension of the tool profile height:

$$h_k = (h_p - 0,5Th_p + C)^{+Th_k}.$$

In the designing of gauges it is recommended to use the following ratios:

if $Th_p < 0,05$ mm $Th_k = 0,4Th_p$, $C = 0,1Th_p$;

if $Th_p = (0,06...0,1)$ mm $Th_k = 0,35Th_p$, $C = 0,15Th_p$;

if $Th_p > 0,1$ mm $Th_k = 0,3Th_p$, $C = 0,2Th_p$.

The calculations are performed for each characteristic point of the gauge from the accepted reference point.

Calculation of the axial executive sizes of the tool and the gauge is performed from the axial executive sizes and the tolerance Tl_d of the workpiece. In this case it is necessary to consider resizing because of the spindle runout with a fixed part in it, wear of the tool and the gauge, as well as that which the linear size - female or male – the workpiece has (Figure 24).

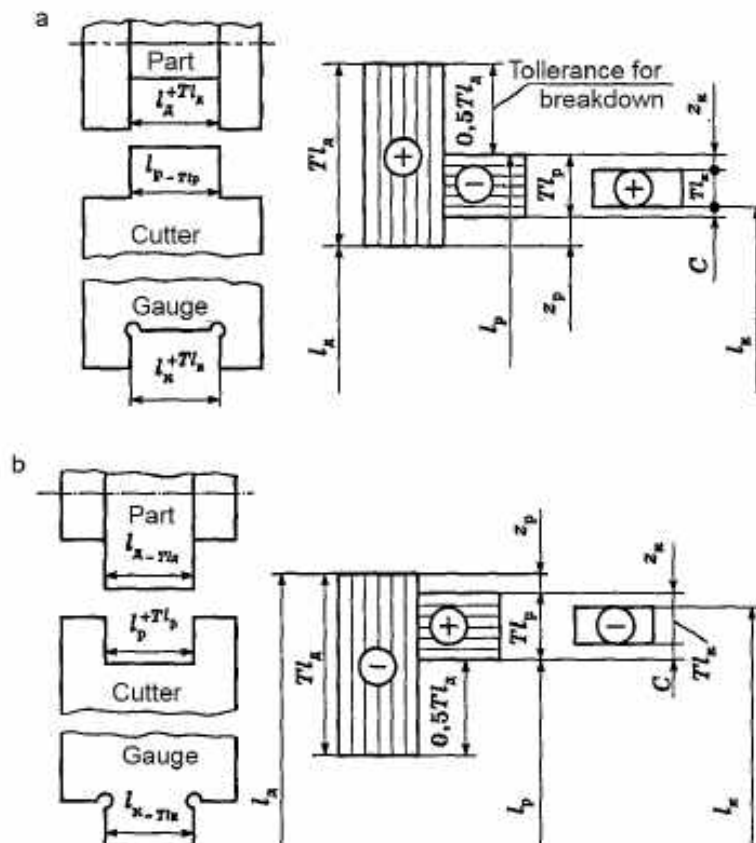


Figure 24 – Linear dimensions and tolerance bands for the part, form tool and the gauge: a – the part is an external member; b – the part is an internal member

If the workpiece has female size I_δ , then the tool has male size and gauge has female size. During the operation the tool wears out and its linear dimension I_p decreases while the gauge linear dimension I_k , on the contrary increases. Therefore, tool should be manufactured with the maximum axial dimension taking into account the spindle "breakdown" and gauge - with the minimum axial dimension, but "visual clearance" C should also be considered:

$$I_p = (I_\delta + 0,5TI_\delta)_{-TI_p}; \quad I_k = (I_p - 0,5TI_p + C)^{+TI_k},$$

where TI_δ , TI_p , TI_k - tolerances on linear dimensions of the workpiece, tool and gauge, respectively; z_p , z_k - tolerances for wear of tool and gauge (see Figure 24). We recommend the following ratios:

$$TI_p = 0,4TI_\delta; \quad TI_k = 0,4TI_p; \quad C = 0,1TI_p; \quad z_p = 0,1TI_\delta; \quad z_k = 0,5TI_p.$$

Similarly we define the linear dimensions of the tool and the gauge considering incoming axial dimensions of the workpiece:

$$I_p = (I_\delta - 0,5TI_\delta)^{+TI_p}; \quad I_k = (I_p + 0,5TI_p - C)_{-TI_k}.$$

Calculation of tolerances for parameters of sharpening and mounting of the tool

For all angles, determining the sharpening and mounting of tool ($\varepsilon = \alpha + \gamma$, α_6 , etc.), tolerances are accepted in minutes of arc which is numerically equal to the lower tolerance on high-level profile size expressed in micrometers. For example, if for the given area tolerance for the profile height is 45 μm , the tolerance angle ε is $\pm 22'$. Tolerance on the height of the mounting of circular tool axis over the axis of the workpiece is determined by differentiating the formula $h = R \sin \alpha$:

$$Th = R \cos \alpha \frac{T\alpha}{3440} = \frac{R(T\alpha) \cos \alpha}{3440},$$

where $T\alpha = T\varepsilon$; value 3440 is used to transfer arc minutes to radians.

In the same way we find the tolerance for value H , determinative correct sharpening of the circular tool:

$$TH = \frac{R(T\varepsilon) \cos \varepsilon}{3440}.$$

Maximum deviations of the structural elements of the form tools are accepted in accordance with well-known recommendations.

General requirements for the homework

1.1. Content of the homework

Doing 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 Tables 8 – 11);

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

1.2. Scope of the homework

The student should defend following documentation according to 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.

1.3. Homework defense

Homework should be defended 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 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.

1.4. 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. The variant of the item material is selected by the number of student in list of his academic group (or by last digit of the record book).

1.5. Form tools

1.5.1. Variants of tasks for the design of form tools (Tables 8 – 11, Figure 25).

Table 8 – Material of the item, processed by the form tool

Variant No.	Material of the item	σ_B , MN/m ²	Variant No.	Material of the item	σ_B , MN/m ²
1	Alloy AL-9	186	10	Alloy VML-1	196
2	Alloy D18T	461	11	Steel 3	450
3	Alloy AL-8	294	12	Steel 5	600
4	Copper	235	13	Steel 45X	1000
5	Steel20	441	14	Steel 40XH	800
6	Brass LT90	265	15	Steel 65Г	750
7	Alloy ML5	265	16	Steel XГ	1000
8	Alloy AMg 11	145	17	Steel 40Г	HB 229
9	Alloy AMts 11	157	18	Steel 50	HB 241

Deviation of sizes take on **h9**.

Table 9 – Form tool tasks

Type of tool		D_1 , mm	D_2 , mm	D_3 , mm	D_4 , mm	l_1 , mm	l_2 , mm	l_3 , mm	l_4 , mm	R , mm
Variant No.										
Flat	Circular									
1	11	15	20	25	15	5	10	15	20	2,5
2	12	20	25	30	15	8	12	18	25	2,5
3	13	22	26	32	25	6	12	18	25	3.0
4	14	25	30	36	30	5	10	15	20	3.0
5	15	28	32	40	30	7	17	25	30	4.0
6	16	30	35	42	35	5	12	18	25	3.5
7	17	32	36	42	30	8	14	20	27	3.0
8	18	35	40	46	35	6	12	20	25	3.0
9	19	40	45	52	40	8	14	22	28	3.5
10	20	45	52	60	45	5	12	18	28	4.0

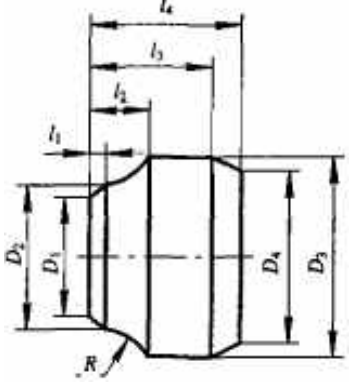


Table 10 – Form tools tasks

Type of tool		D , mm	l_1 , mm	l_2 , mm	R , mm
Variant No.					
Flat	Circular				
1	11	60	5	11	19
2	12	65	6	14	22
3	13	70	7	18	30
4	14	75	7.5	20	32
5	15	80	8	21	35
6	16	80	8	23	35
7	17	85	9	25	35
8	18	85	9	30	40
9	19	90	9	30	45
10	20	90	10	35	50

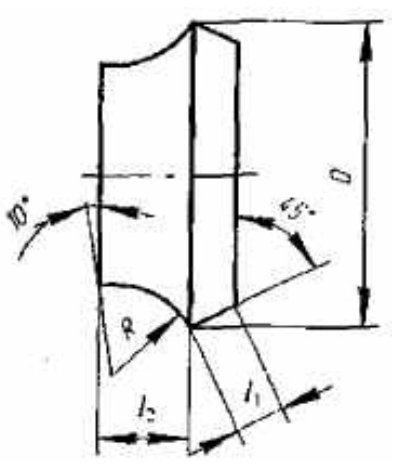


Table 11 – Form tool tasks (Figure 25)

Type of tool	Variant No.	D_1 , mm	D_2 , mm	D_3 , mm	D_4 , mm	D_5 , mm	l_1 , mm	l_2 , mm	l_3 , mm	l_4 , mm	l_5 , mm
1	11	20	15	10	10	15	5	10	15	20	25
2	12	25	20	20	15	20	6	12	15	20	25
3	13	30	25	20	10	15	6	10	15	22	27
4	14	35	30	25	10	20	7	10	16	25	30
5	15	36	31	28	15	28	8	12	15	21	27
6	16	38	21	18	15	30	5	10	15	20	25
7	17	40	25	20	25	30	6	12	15	20	28
8	18	45	30	20	20	30	5	18	12	20	25
9	19	50	35	20	25	30	8	16	20	25	30
10	20	55	45	30	15	25	10	15	20	25	35

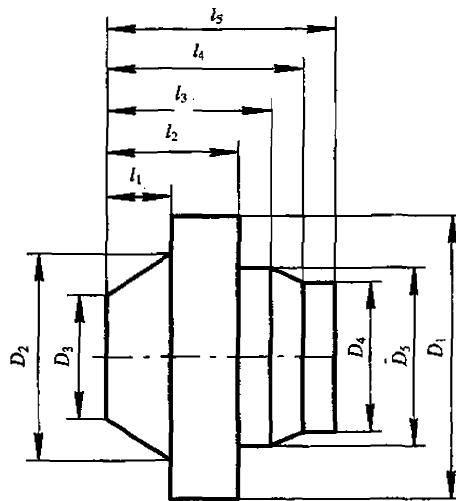


Figure 25 – Form tool geometry

1.5.2. Perform working drawing of the workpiece at 1:1 or 2:1 scale with dimensioning at all nodal points by which corrective calculation will be done.

Assign the material for the tool depending on the workpiece material.

Taking into account tool and workpiece material assign the rake angle γ at the point that will process the smallest diameter of the item.

Assign relief angle α for the same point. In setting the relief angles we should be aware that in the sections normal to the cutting edges their values were obtained at least 2 ... 3 °.

1.5.3. Choose and explain the design of the tool and the way to fix it in the tool holder.

1.5.4. Calculate the dimensions of the tool:

a) determine the depth of workpiece profile in the radial direction;

b) determine the diameter of the mandrel for the circular tool. To do this, depending on the cutting conditions and requirements for the surface roughness feeds are prescribed and cutting forces are determined. Diameter of the mandrel is selected from tables or calculated by the force of cutting and mounting technique;

c) count the outer diameter of the circular form tool.

The parameters of flat form tool are calculated by formulas or selected from tables depending on the depth of the profile and width of the workpiece. When appointing the width of the tool, both circular and flat, it is necessary to take into account the width of additional cutting edges on the edges of the cutter (for chamfering and designation cutting area of the workpiece from bar).

1.5.5. Perform graphical calculation of the tool profile.

1.5.6. Count the rear angles in various points of the tool profile in sections perpendicular to the projected cutting edge on the radial plane, and plot graph of their changes. For this purpose, values of angles are plotted on the ordinate, the axial dimensions between the angular points of the profile – on the abscissa. According to the obtained graph do a conclusion about the possibility of tool proper operation or take additional measures to improve the geometry of the tool.

1.5.7. Perform working drawing.

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