TOMSK POLYTECHNIC UNIVERSITY

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MATERIAL CUTTING AND CUTTING TOOLS

COURSEWORK GUIDELINES

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ANNOTATION

"Material Cutting and Cutting Tools" Coursework guidelines are designed for students enrolled in the Bachelor Degree program 150700 "Mechanical engineering". The coursework is designed to be performed in two semesters

The guidelines contain the instructions for designing of circular form cutters and round rotor-cut broaches, initial data and examples of drawings.

CONTENTS

1. Form Cutters

1.1 Overview

Form cutters are applied for cutting of circular parts with profiled external or internal surfaces. The form cutters are usually used in automatic machines and turret machines in medium run production or mass production. Calibrated rolled bars are most often used as blankets for the form cutting.

Compared with other types of cutters, the from cutters have the following advantages: 1) identity of the part shapes and high dimensional accuracy independent of the qualification of the worker; 2) high productivity due to great length of the active cutting edge; 3) large number of allowable regrindings; 4) simple regrinding along the face surface; 5) do not require time-consuming set-up and configuration of the machine tools.

The disadvantages of form cutters include: 1) complicated manufacture and high cost; 2) special design, as they are suitable for the manufacture of parts only of the specified profile; 3) large radial forces caused by radial feed, result in chatter and elastic deformation of non-rigid workpieces, thus requiring feed rate reduction, which in its turn decrease the productivity; 4) working rake and clearance angles of the form cutters vary considerably along the cutting edges from the optimal values.

Form cutters are of the following types (Fig. 1.1): radial, circular, radial prismatic and tangential prismatic. Of these, the most common are the circular and prismatic cutters working with radial feed.

Analysis of radially fed circular and prismatic cutters design shows that the circular cutters are easier to manufacture and thus, can be made of higher precision. However, the number of regrindings and mounting rigidity is limited, since the cutter bore diameter depends on the outer diameter of the cutter. The latter is recommended to assign of smaller than 100 mm in diameter, since the quality of high-speed steel used for the manufacture of cutters of such size is deteriorated. Prismatic cutters have greater stiffness and clamped with help of dovetail shank, they have a large number of permissible regrinding and, as it will be shown below, provide higher accuracy of machining.

For cutting internal form surfaces only circular shank-type form cutters are used.

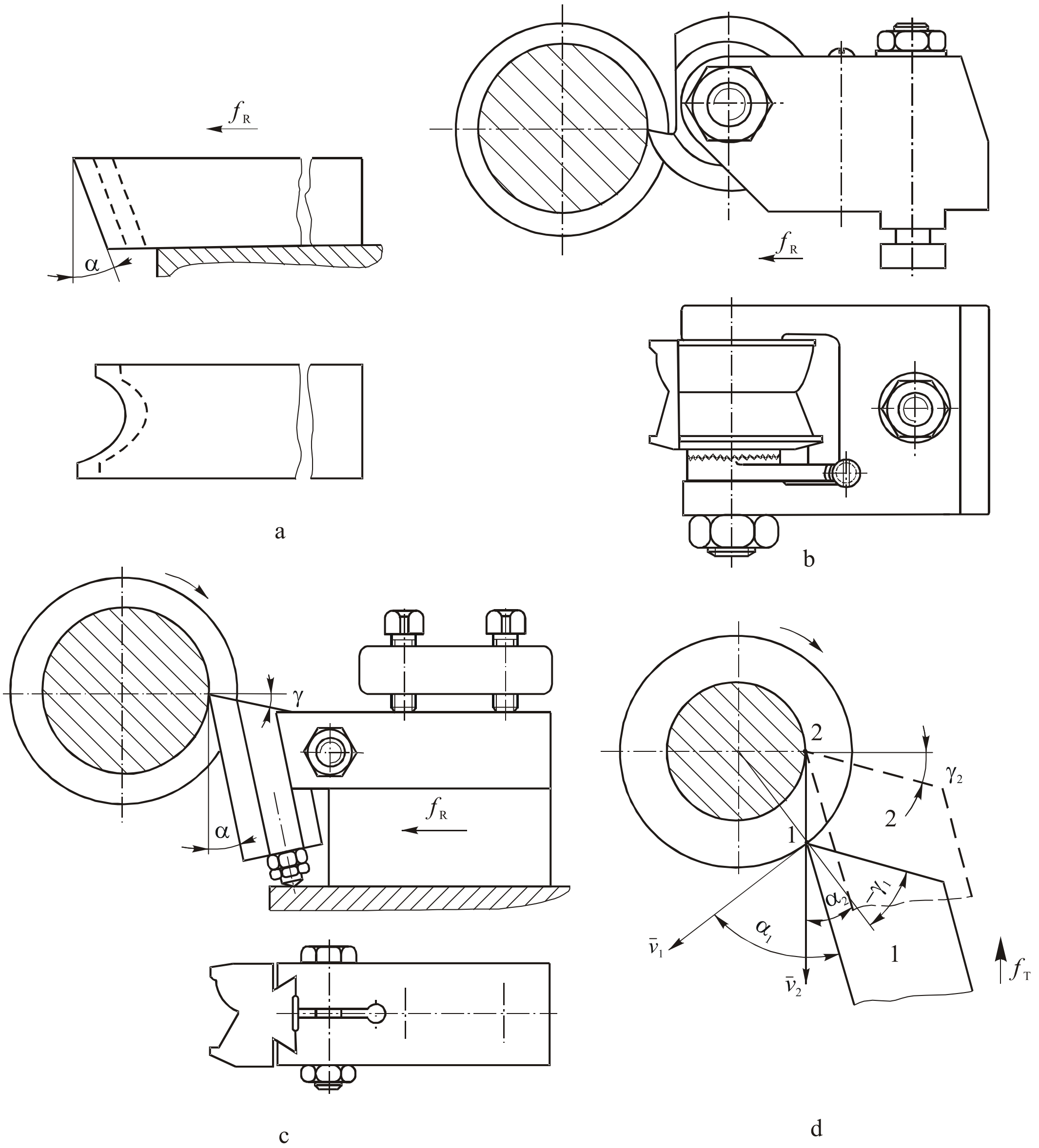


Fig. 1.1 Form cutters: (a) radial; (b) circular;
(c) prismatic; (d) tangential prismatic

The clearance angle α of the circular form cutters is created by positioning the center of the tool O_C above the center of the workpiece O_W by the height h, and the rake angle γ is created by grinding the rake surface at the distance H from the center O_C (Fig. 4.6). In the example the points located on the outer diameter of the cutter (points 1 and 3) lie on the center line of a machine:

$$\sin\alpha = h/R,\ \sin(\alpha+\gamma) = \sin\psi = H/R,$$

where R – is the radius of the cutter outer diameter.

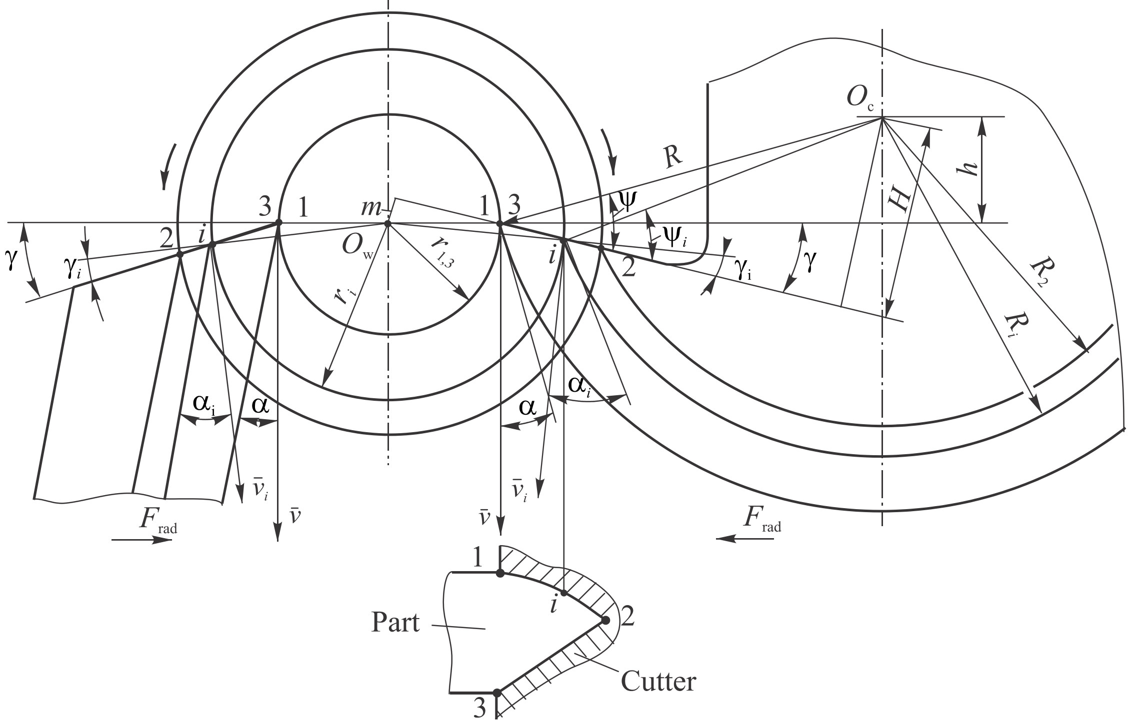


Fig. 1.2 Geometric parameters of a circular (right) and a prismatic (left) form cutters, which work with radial feed

At other points of the cutting edge the angles α and γ, measured in a section perpendicular to the axis of the cutter, depend on the position of the reference planes (reference plane and cutting edge plane) and tangents to the face and flank surfaces of the cutter. Tangent to the flank surface drawn at different points along the cutting edge – is a normal to the radius, drawn from the cutter center O_C.

It follows from the above that with the point of the cutting edge approaching to the center of the tool the coordinate planes rotate in a clockwise direction and, thus clearance angle is $\alpha_i > \alpha$ and rake is $\gamma_i < \gamma$ in any ith point located at a distance from the cutter top. Tangents to the flank of a circular cutter also rotate, but in the opposite direction, i.e. counterclockwise.

Position of the prismatic cutter during the cutting process is shown on the left side of Fig. 1.2. During the manufacture of these cutters the face is cut at an angle γ+α, and the actual clearance angle α in the working position is created by tilting the tool relative to the part.

Clearance angles of the inclined cutting edges are usually measured in sections normal to these edges. In order to avoid friction between the flanks and machined surface clearance angles should be at least 1...2° (Fig. 1.3, a).

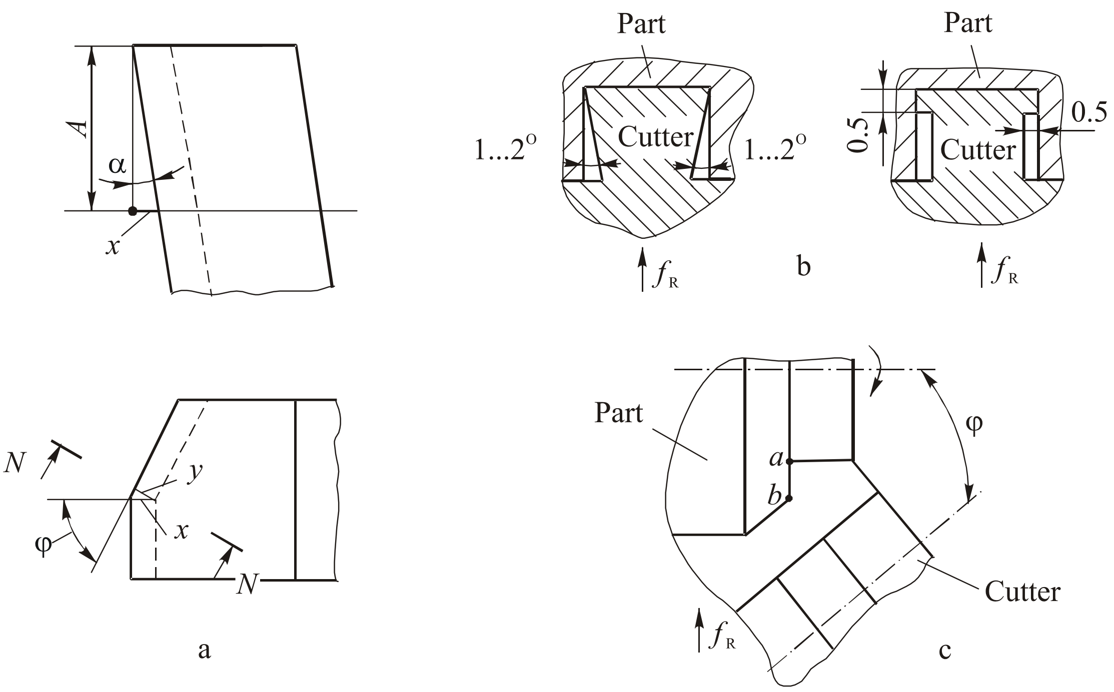


Fig. 1.3 Clearances of the form cutters: (a) clearance angles on inclined cutting edges; (c) undercut on the cutting edges perpendicular to the workpiece axis; (c) cutter with inclined profile

To avoid rubbing of cutter side flanks against the surface of the workpiece the cutting edges that perpendicular to the axis of the workpiece are either undercut at an angle φ_1=1°...2°, or cut away with only the narrow ribbon of width f=0.5...1.0 mm left (Fig. 1.3, b). It is also possible to manufacture cutters helical flanks or with cutter profile inclined at an angle relative to the axis of the workpiece (Fig. 1.3, c), in order to create more desirable clearance angles on such cutting edges.

Profiling of form cutters (analytical calculation of the profile) is performed at the stage of manufacturing, as well as during designing tools of the second order, templates and reference templates that are used to check profiles of the cutters and templates respectively. Circular cutters profile is calculated in the radial section, and the prismatic cutters are calculated in a section normal to the flank. In this case, because of the variable angles α and γ the depth (height) of the cutter profile in these sections does not match the part profile depth in its axial section.

1.2 Profiling of form cutters

Initial data: part drawing (Appendix 1).

Calculation procedure

1. Selection of the tool material. The common tool material is high speed steel grade P6M5 (GOST 19265-73), hardened to *HRC* 63…66. For machining of hardened steels it is advised to apply HSS grades P18 and P6M5K5, P9M4K8 etc.
2. The rake γ_1 is assigned for the top point of the cutter (Table 1.1).

Table 1.1

1.1. Rakes angles for the form cutters

Workpiece material	σ, MPa	Hardness, *HB*	Rake γ_1, deg.
Copper, aluminum	–	–	20...25
Mild steel	до 50	до 150	25
Free-machining steel (A12, A20 etc.)	50...80	150...235	20...25
Medium-hard steel	80...100	235...280	12...20
Hard alloyed steel	100...120	280...350	8...12
Malleable cast iron (ferritic)	–	до 150	15
Gray cast iron	–	150...200	12
Bearing cast iron	–	200...250	8

Clearance angle for the profile highest point of the prismatic cutters is taken within α_1=12...15°, and for the circular cutters – within α_1=10...12°. Rake γ_i and clearance α_i angles at other points of the cutting edge are variable. The farther the point of the profile is from the top of the tool, the smaller is the rake and the higher is the clearance angle. In profile sections perpendicular to the part axis the angle α=0°. In this case, to avoid severe friction it is required to create undercut angles equal to 1...2° (Fig. 1.4, b).

3. Dimensions and parameters of the mounting part of the cutter are assigned with respect to the maximum height t_{max} of the part profile (Tables 1.2–1.4) [2]. The tabular value of the circular form cutter radius is verified with the help of the following equation (Fig. 1.5):

$$R_1 = t_{\max} + K + e + d_0 / 2,$$

where t_{max} – maximum depth of cut of the part profile; K – chip room, K=3…12 mm; e – wall thickness, e=5…8 mm; d_0 – diameter of the cutter bore (Table 1.5).

Further, the calculated value R_1 is rounded to integer and is accepted as the maximum radius of the circular form cutter.

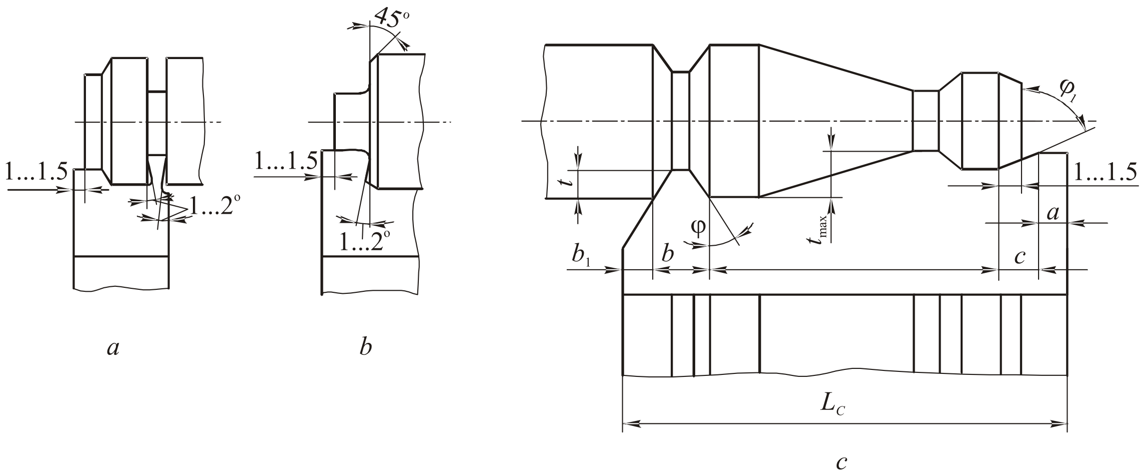


Fig. 1.4 Minor cutting edges of the from cutters:
(a) for grooving; (b) for chamfering; (c) profile turning (a=2…5 mm, c=1…3 mm, *φ_1=15…20°, b≥3…8 mm, b_1=0.5…1.5 mm, φ=15°)*

4. Further, the altitude coordinates of the part profile points are calculated. These altitude coordinates are specified by the radii that depend on the size tolerances of the given point. Thus, the nominal radius of the i^{th} point is calculated by the equation:

$$r_i = \frac{d_{i\max} - d_{i\min}}{4},$$

where $d_{i\max}$ – maximum limit of size; $d_{i\min}$ – minimum limit of size.

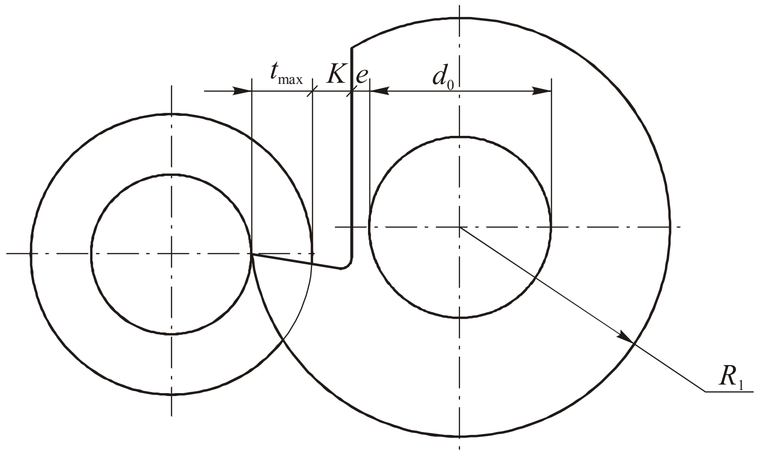


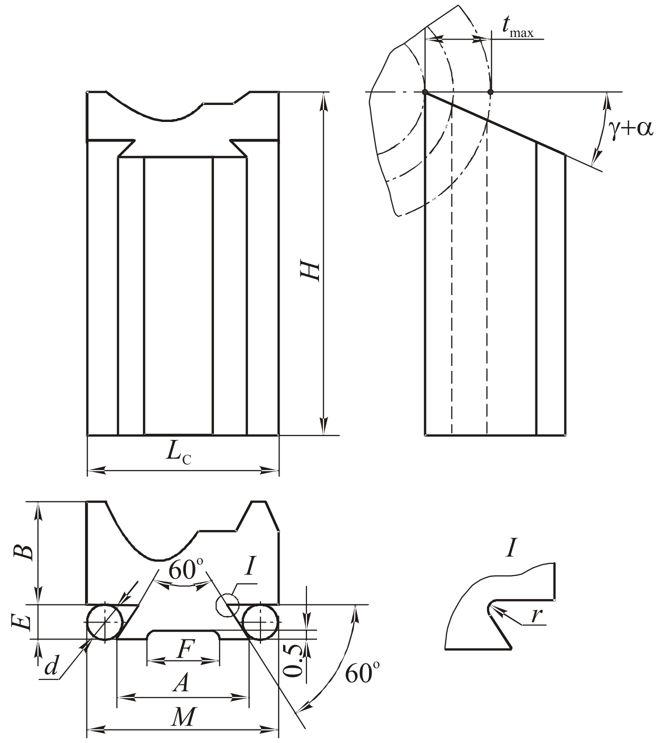
Fig. 1.5 Schematic for estimation of the outer radius R_1 of circular form cutter

All calculations must be performed to three decimal places and then rounded to the two decimal places.

5. Since rake γ and clearance α angles are not zero, the cutter profile differs from the part profile, and, thus, should be corrected. Form cutter profile is calculated and checked in planes that perpendicular to the flank surface (prismatic cutters) and radial planes (circular cutter).

Table 1.2

Dimensions of prismatic form cutters



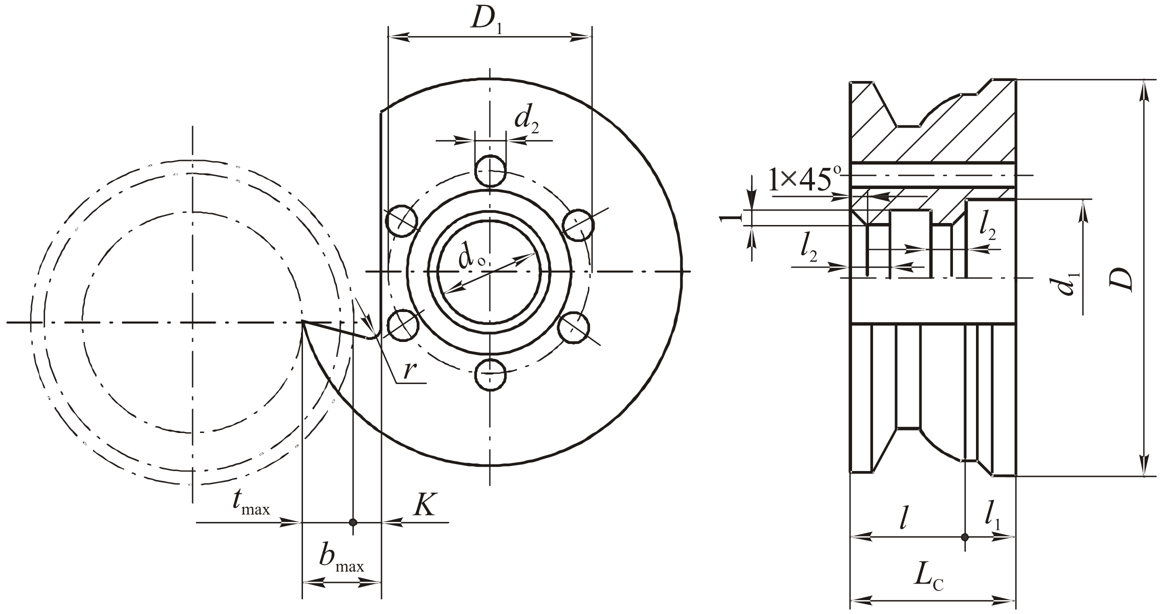
Part profile height t_{max}, no more than	B, mm	H, mm	E,mm	A mm	F mm	r mm	d, mm	$M(h9)$, mm
4	9	75	4	15	7	0.5	4 3	21.31 18.577
6	14		6	20	10		6 4	29.46 24.00
10	19	90	10	25	15	1.0	6 4	34.46 29.00
14	25			30	20		10 6	45.77 34.846
20	35			40	25		10 6	55.77 44.846
28	45	100	15	60	40		15 8	83.66 64.536

Note:

1. It is allowed for given part profile height t_{max} to choose cutters of bigger sizes, for example, for a part with profile height t=7 mm it is permissible to choose cutters with sizes that are meant for $t_{max} \leq 14$ мм.
2. Length L_C relates to the part profile length.
3. The shank size M can be controlled with rollers of two diameters. For rollers of another diameter: $M = A + d\left(1 + \mathrm{ctg}\frac{\lambda}{2}\right) - 2E\,\mathrm{ctg}\lambda$, where λ=60° (for a given drawing).

Table 1.3

Dimensions of circular form cutters with pin holes



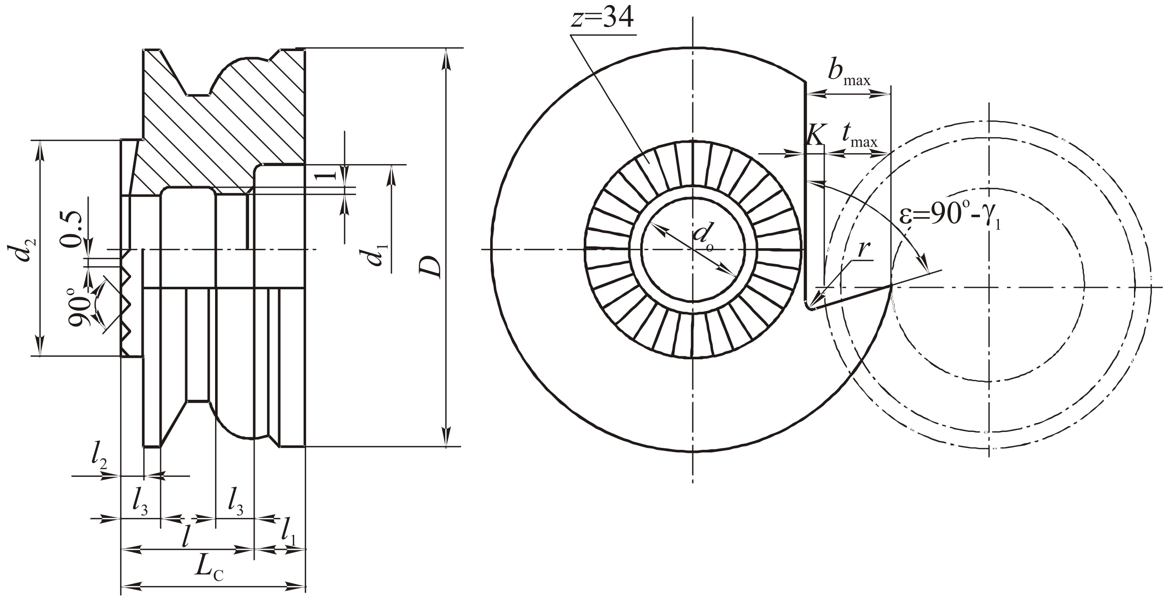
Part profile height t_{max}, no more than	$D(h9)$, *mm*	$d_0(H8)$, *mm*	d_1, *mm*	b_{max}, *mm*	K, *mm*	r, mm	D_1, *mm*	d_2, *mm*
6	50	13	20	9	3	1	28	5
8	60	16	25	11		2	34	
11	75	22	34	15	4	2	42	
14	90			18		2	45	6
18	100	27	40	23	5	2	52	8
25	125			30		3	55	

Note:

1. It is allowed for given part profile height t_{max} to choose cutters of bigger sizes (refer to Notes 1 for Table 1.2).
2. Length L_C relates to the part profile length.
3. Sizes: $l=L_C-l_1$; $l_1=\left(\frac{1}{4}...\frac{1}{2}\right)L_C$; $l_2=\frac{1}{4}l$.

Table 1.4

Dimensions of circular form cutters with end serrations



Part profile height $t_{\max}$, no more than	$D(h9)$, *mm*	$d_0(H8)$, *mm*	d_1, *mm*	b_{max}, *mm*	K, *mm*	r, mm	d_2, *mm*	l_2, *mm*
4	30	10	16	7	3	1	–	–
6	40	13	20	10			20	3
8	50	16	25	12	4	2	26	
10	60			14			32	
12	70	22	34	17	5	2	35	4
15	80			20			40	
18	90			23			45	5
21	100	27	40	25			50	

Note:

1. It is allowed for given part profile height t_{max} to choose cutters of bigger sizes (refer to Notes 1 for Table 1.2).
2. Length L_C relates to the part profile length.
3. Sizes: $l = L_C - l_1$; $l_1 = \left(\frac{1}{4}...\frac{1}{2}\right)L_C$; $l_3 = \frac{1}{4}l$.

Table 1.5

Bores of circular form cutters

D^{table}, mm	30	40	50	60	75	90
d_0, mm	13	16	16	22	22	27

The profile correction is performed as follows.

a) Common part: it is necessary to calculate the height of the cutter (circular or prismatic) profile in a face plane, i.e. the distances C_2, C_3, C_4 ... of the corresponding part profile points 2, 3, 4 ... (Fig. 1.6):

1) $h = r_1 \sin\gamma_1$; 2) $A_1 = r_1 \cos\gamma_1$;

3) $\sin\gamma_2 = \dfrac{h}{r_2}$; 4) $A_2 = r_2 \cos\gamma_2$; 5) $C_2 = A_2 - A_1$;

6) $\sin\gamma_i = \dfrac{h}{r_i}$; 7) $A_i = r_i \cos\gamma_i$; 8) $C_i = A_i - A_1$;

and so on for the other points.

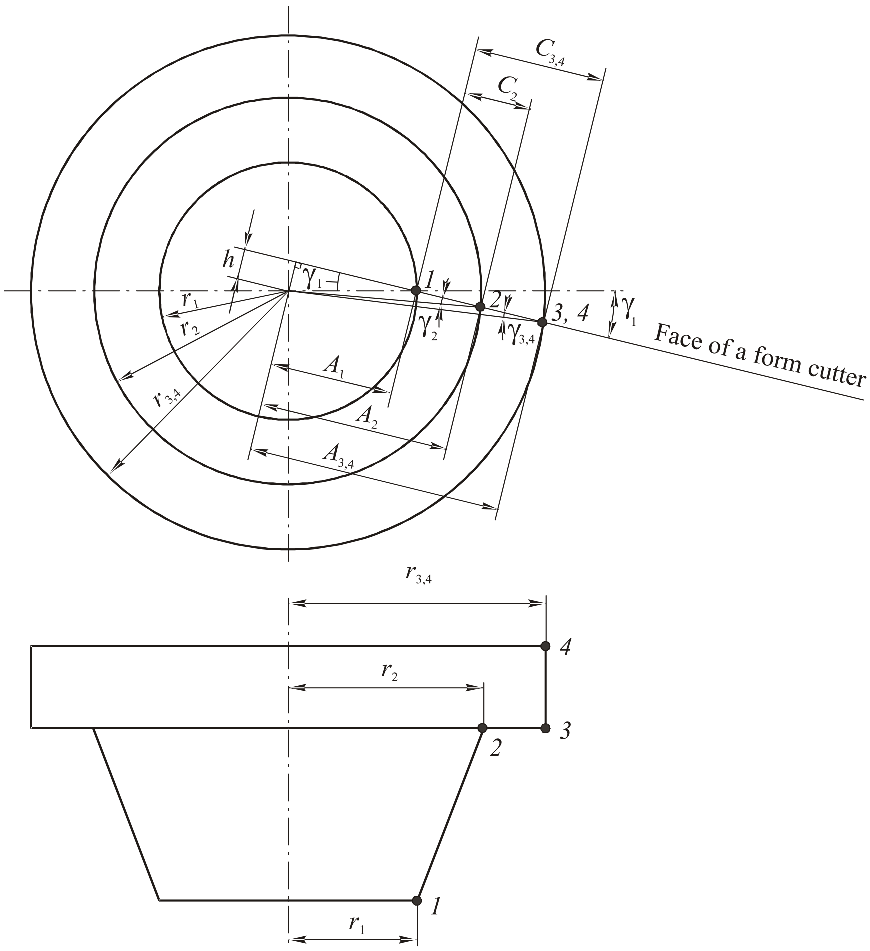


Fig. 1.6 Schematic for calculation of the cutter profile height C_2, C_3, C_4, ...

b) For prismatic cutters: it is necessary to calculate the height of the cutter profile in a plane perpendicular to the flank, i.e. the distances P_2, P_3, P_4 … of the corresponding part profile points 2, 3, 4 … (Fig. 1.7):

1) $\varepsilon_1 = \alpha_1 + \gamma_1$; 2) $P_2 = C_2 \cos\varepsilon_1$; 3) $P_i = C_i \cos\varepsilon_1$.

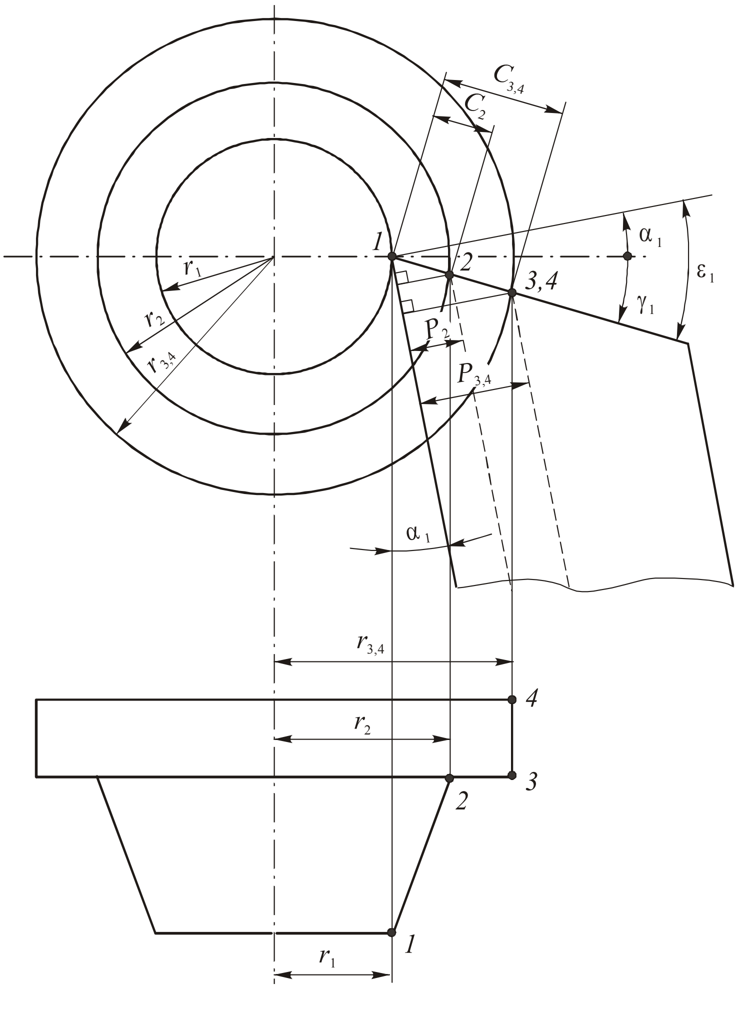


Fig. 1.7 Schematic for calculation of the prismatic cutter profile height P_2, P_3, P_4, etc. in a plane perpendicular to the cutter flank

c) For circular cutters: it is necessary to calculate radii R_2, R_3, R_4 ... of the corresponding part profile points 2, 3, 4 ... (Fig. 1.8):

1) $\varepsilon_1 = \alpha_1 + \gamma_1$; 2) $h_C = R_1 \sin\varepsilon_1$; 3) $B_1 = R_1 \cos\varepsilon_1$;

4) $B_2 = B_1 - C_2$; 5) $\mathrm{tg}\,\varepsilon_2 = h_C / B_2$; 6) $R_2 = h_C / \sin\varepsilon_2 = B_2 / \cos\varepsilon_2$;

7) $B_i = B_1 - C_i$; 8) $\mathrm{tg}\,\varepsilon_i = h_C / B_i$; 9) $R_i = h_C / \sin\varepsilon_i = B_i / \cos\varepsilon_i$;

and so on for the other points.

6. Further, the cutter cutting edges profile is drawn on M 2:1 scale. The outermost cutting edges of the cutter profile cut a chamfer and a groove for cut-off cutter. Here, the groove diameter should not be less than the minimum diameter of the part.

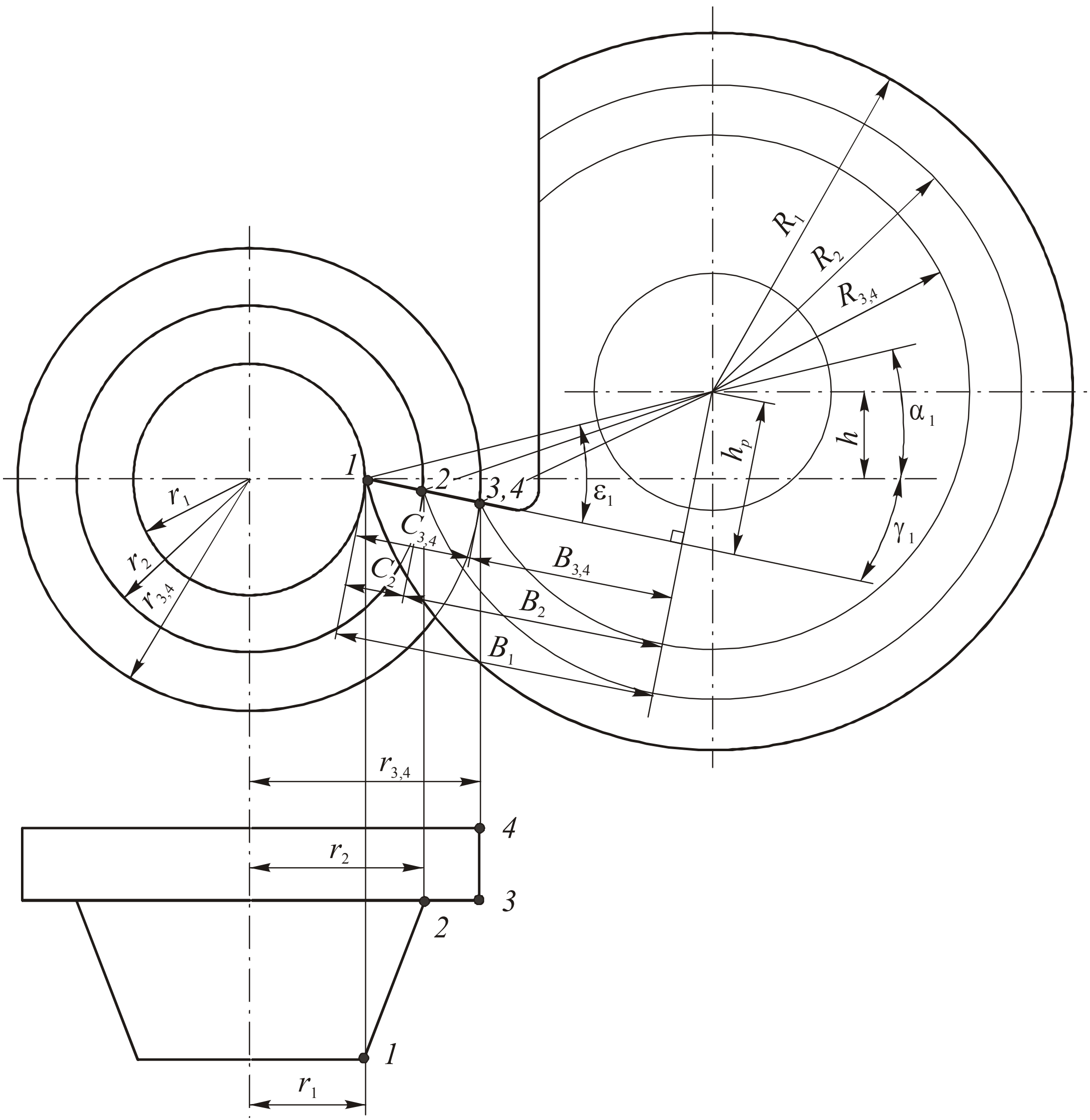


Fig. 1.8 Schematic for calculation of the circular cutter radii R_2, R_3, R_4 …

In the drawing the altitude coordinates of the profile points are positioned with respect to the datum that is the highest profile point; and the axial coordinates, which are converted from the axial dimensions of the part, are plotted with respect to the rightmost profile point.

The accuracy of the height dimensions is set equal to ±1/3Δ, where Δ – tolerance value of the corresponding dimension of the part. The accuracy of the cutter axial dimensions is set equal to ±*IT*12/2.

7. Finally, the drawing of the form cutter is made and the calculations report is written. The prismatic form cutter is drawn in three projections (App. 2). The circular form cutter is represented in two projections with obligatory designation of the parameters h and H, which define values of the angles α_1 and γ_1 in the highest point of the cutter (App. 3).

2. Internal broaches

2.1. Overview

Broaches are multiple-point high productive cutting tools, widely used in the medium run production and especially in mass production. Broaches have inherent feed motion, since the machine performs only the pulling motion without feed available. The allowance distribution between the teeth of a broach is implemented by the progressive increase of height or width of each subsequent tooth relative to the previous one. The increase in height, which specifies thickness of chip a_z, is called feed per tooth or rise per tooth. The chips are divided by width with the help of chipbreakers to facilitate the process of cutting and chip removal.

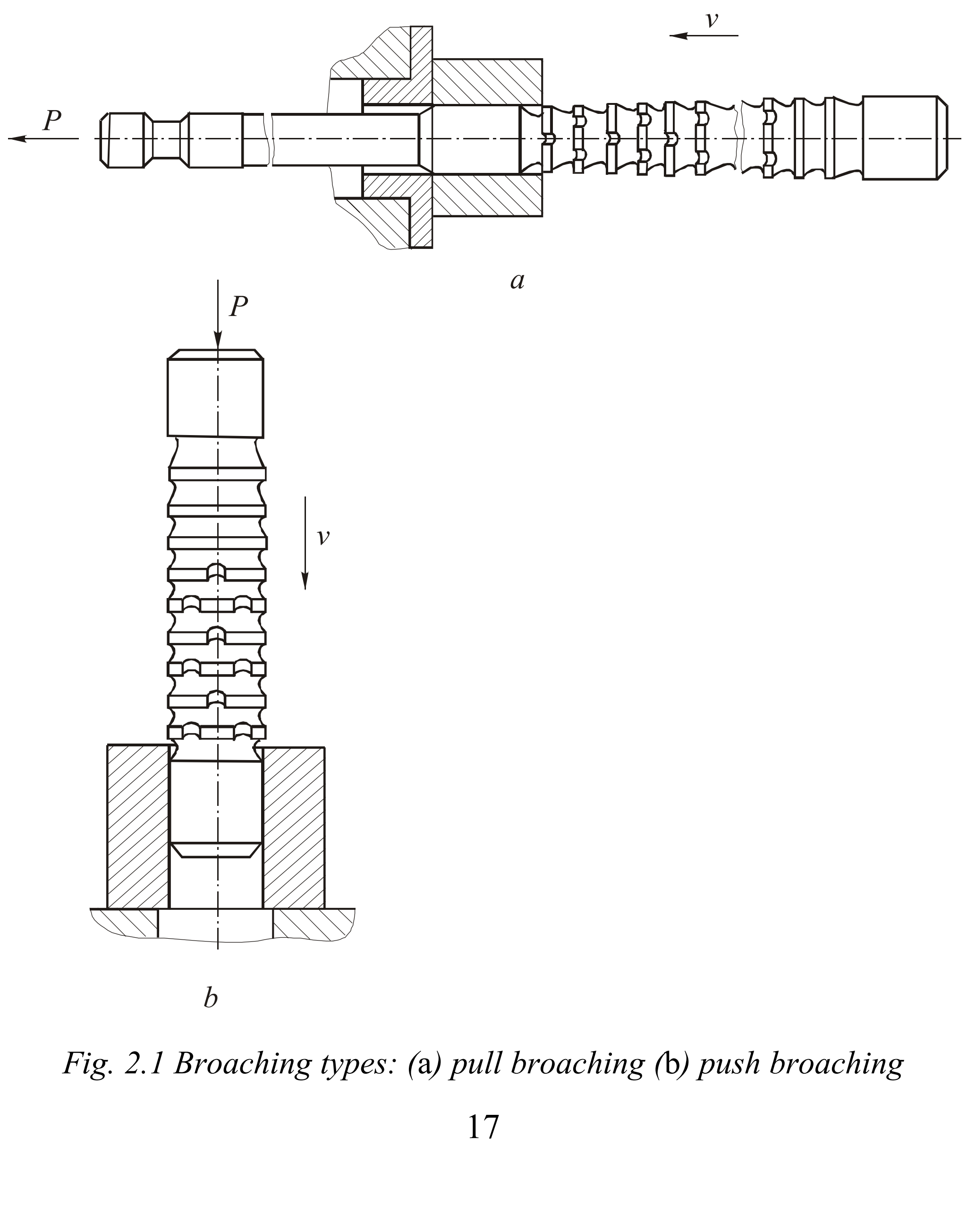


Fig. 2.1 Broaching types: (a) pull broaching (b) push broaching

The primary motion of broaching, that performs process of cutting, is often straight-line linear motion. Less common types of broaches involve rotational or helical primary motion.

The process of broaching is carried out in special horizontal or vertical broaching machines.

Round holes can be cut with pull broaches (Fig. 2.1, *a*) or push broaches (Fig. 2.1, *b*). The pull broaches work in tension and push broaches work in compression. Thus, the push broach length is limited by 15 diameters to ensure buckling stability. The structure of the push and pull broaches is similar.

The broaches spread widely due to the following advantages of the broaching process:

1) high productivity. The active length of the cutting edges is very large, although the cutting speed is low (6...12 m/min). In general the productivity of broaching is in 3...12 times higher than for other types of machining;
2) high accuracy (*IT*7...*IT*8) and surface finish (*Ra* 0.32...2.5 μm) of the machined surface, due to broach design with separate roughing, finishing and sizing teeth, and in some cases even with burnishing buttons;
3) high tool life, which is up to several thousands of parts. This is achieved by the optimal cutting conditions and large stock for regrinding;
4) simple design of broaching machines, since there is no need for feed motion, so the machines do not have feed gearboxes, and the primary motion is performed by hydraulic rams.

The disadvantages of broaches include:

1) high labor and cost of a broach due to complex design and high accuracy requirements;
2) broaches are special-purpose tools, designed for manufacture of parts of only one size and given shape;
3) the high cost of regrinding, caused by the complexity of the broach design.

Therefore, cost-effectiveness of applications of broaches is achieved only in medium-production and mass production. Nevertheless, even small enterprises working in conditions of single-part or medium run productions can achieve significant economic efficiency provided that the broaching is used for production of complex shaped precision holes.

During the design of broaches the following peculiarities of the broaching process should be considered:

1) broaches experience large tensile loads, and therefore internal broaches should be checked for strength of the weakest cross-sections;
2) the entire chip produced by a broaching must be freely contained in the gullets for the whole period of broaching, and should be easily leave the gullets after the broaching process is finished. Therefore, issues of chip breaking and accommodation require a lot of attention. So, for example, the ring-shaped chips are not allowed in broaching round holes, since it would be quite time-consuming to release broaches from them;
3) the length of broaches is limited by the broaching machine stroke and technological capabilities of machines and equipment used for machining and heat-treatment of the broaches. Moreover, broaches must be stiff and rigid enough for the manufacture and operation, so rests and other supporting devices are sometimes used in broaching.

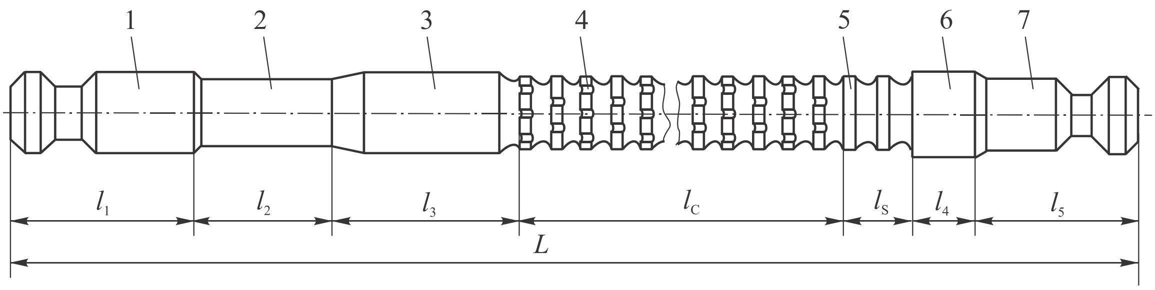


Fig. 2.22 Construction of an internal broach: (1) pull-end; (2) neck; (3) front pilot; (4) cutting part; (5) sizing part; (6) rear pilot; (7) retriever

The broaches for round holes are the most widespread (60%) of all internal broaches. The construction of internal broaches includes: pull-end, neck, front pilot, cutting and sizing parts and retriever (Fig. 2.22).

The **pull end** is used to couple the broach to the puller of the broaching machine. Basic types and sizes of a pull end are standardized (GOST 4044-70). The diameter of the pull end should be smaller by 1...2 mm than the diameter of the starter hole for broaching.

The **neck** and the following **transition cone** play a supplementary role. Their length should ensure broach coupling with the machine puller before the broaching has started. Transition cone provides free entry of the front pilot to the starter hole. Neck diameter is taken smaller than the shank diameter by 0.3...1.0 mm.

Front pilot aligns the axis of the workpiece relative to the axis of the broach before pulling. The length of the front guide is equal to the workpiece hole length L_0, and for longer holes it is equal to $0.6L_0$. Tolerance of the front pilot diameter is $e8$.

Rear pilot ensures broach alignment as the final teeth exit the workpiece hole. The length of the rear pilot is slightly smaller than the front pilot length, and its diameter is machined with $f7$ tolerance zone.

A **retriever** is used to return the broach to starting position automatically after the broaching, especially if a broach of large length and diameter is used.

Cutting part of a broach contains roughing and finishing teeth, with intermediate teeth added for the rotor-cut broach, which are located on a step-conical surface. The length of the cutting part is the result of the number of teeth multiplied by their pitch, which, in turn, depends on the required accuracy and surface finish of the hole, as well as on the volume of material to be cut.

Sizing part contains 4...10 teeth of the same diameter, i.e. with zero rise per tooth. It is used to size or calibrate the hole, reduce the hole size distribution, and is a reserve for finishing teeth regrinding, thereby increasing the broach overall life.

The design of the cutting part is determined by the **cutting pattern** adopted, which refers to the procedure for successive allowance removal.

There are the following cutting patterns: a) by the method of dividing the thickness and width of the allowance – there are standard and rotor-cut patterns; b) by the method of a hole profile forming – there are full-form, generating and combination patterns.

The **standard cutting pattern** is characterized by the fact that each tooth of a broach cuts allowance of a certain thickness around the whole perimeter of the hole, with the diameter of each subsequent tooth being larger than the diameter of the previous by the value $2a_z$, where a_z – is rise or feed per tooth (a_z=f_z).

Since the ring-shaped chip is unacceptable, the chips are to be divided by its width with the help of the V-shaped notches (Fig. 2.3, a), which are arranged in a staggered fashion on the adjacent teeth. Thus the chips removed by the tooth are separate segments with an incorporated stiffening rib with thickness $2a_z$ due to the fact that the notch of the previous tooth leaves this part of the chip uncut. The ribs impair chips curling in the gullets between the teeth, thus the rise per tooth (RPT) is considerably reduced, which in its turn leads to an undesirable increase in the length of a broach.

To create clearance angles on the bottom edges of the chip breaking notches, the latter are cut by a grinding wheel with the broach rear part ramped at a 2…3° angle.

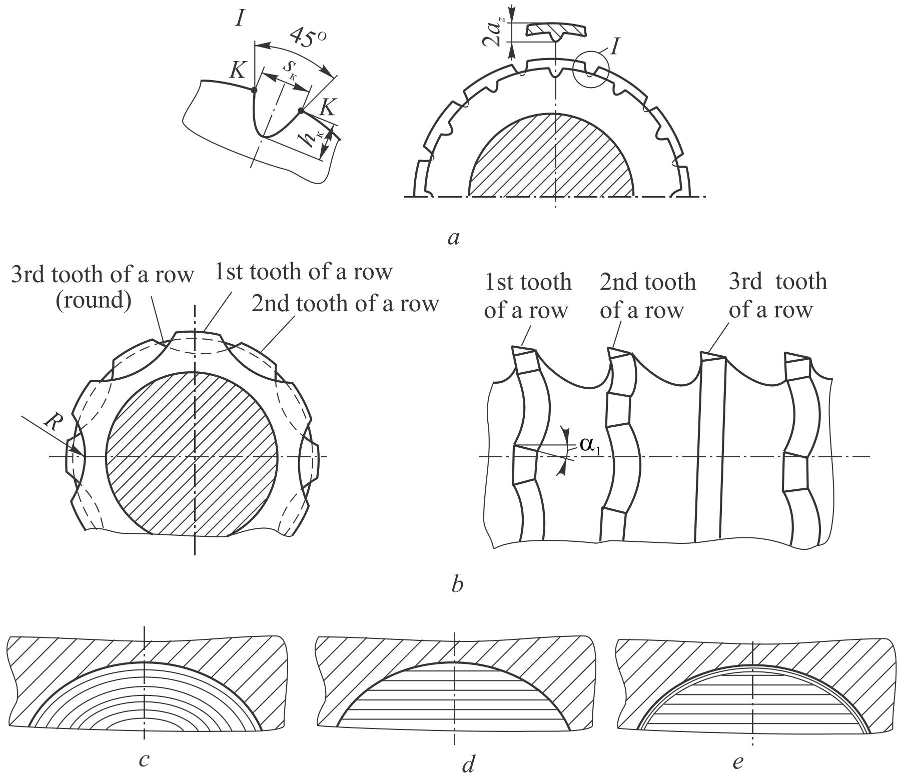


Fig. 2.3 Cutting patterns of broaching: (a) standard; (b) rotor-cut; (c) full-form; (d) generating; (e) combination

The **rotor-cut pattern** (also known as rotary-cut, rotor-kut, jump-cut) differs from the above by the fact that all cutters are divided into groups or rows, consisting of 2...5 teeth, within the limits of which the teeth have the same diameter (Fig. 2.3, b). The allowances thickness is divided between the rows of teeth, and the width of chip is divided between the teeth of a row with the help of chip breaking notches or slots, which are deeper and wider compared to the notches of a standard broach, and a positioned in a staggered fashion. Each tooth removes segments of chip by its cutting edges. Due to wider slots, the chip being cut has no stiffening ribs, providing improved chip curling in the gullets between the teeth even with the RPT considerably increased.

The rotor-cut broaches are significantly shorter compared to the standard ones.

The last tooth in a row is a cleaning tooth with no slots and 0.02...0.04 mm reduce in diameter relative to the other teeth of a row. This is necessary to avoid the formation of ring-shaped chip, which is the result of elastic spring back of the machined surface after the passage of slotted teeth.

The disadvantage of the rotor-cut pattern is the increased complexity of the broach manufacture compared to the standard pattern.

In the **full-form pattern** (Fig. 2.3, c) the profile of the cutting edges is similar to the profile of the hole being broached. Here the final formation of the surface is performed only by the last tooth, and the rest serve to remove the stock. The application of the full-form pattern for complex shapes of the workpiece hole is impractical, since it complicates the manufacture of the broach. Full-form pattern is generally used for surfaces of simple form, such as round or flat.

In **generating (or nibbling) pattern** of broaching (Fig. 2.3, d) the form of the cutting edges is not identical with the workpiece hole profile, which is formed as the envelope of a series of all teeth cutting edges. In this case, the production of a broach is simplified, since all the teeth are shaped by the same grinding wheel of a single profile. However, the broached surface may incorporate scratches (steps) due to the errors of teeth grinding, which degrades the finish of the machined surface.

In case of high requirements for surface finish it is recommended to apply a **combination broach** (Fig. 2.3, e), which two or three last cutting and sizing teeth are full-form, and the rest are generating.

Broach performance is attributed to the selected teeth form and dimensions of the chip breaking grooves.

Teeth of a broach must meet the following basic requirements:

1) the size of the teeth should provide the greatest possible number of regrindings;
2) the tooth must have a certain margin of safety, and thus resist the acting forces;
3) the shape and size of gullets should provide chip curling into a tight coil, and the volume of the gullets must provide sufficient room for chips cut during tooth contact with the workpiece;
4) have a geometry with the greatest broach life provided.

The size of teeth and gullets is limited by the permissible values of the broach length and strength.

Fig. 2.4 shows the most common forms of teeth and gullets: tooth with a straight back, circular back, flat bottomed gullet.

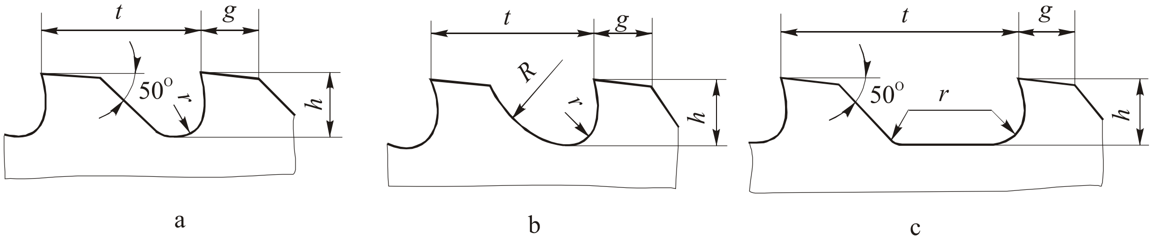


Fig. 2.4 Profiles of teeth and gullets:
(a) tooth with straight back; (b) circular back; (c) flat bottomed gullet

The **teeth with straight back** are simple to produce, but impair chip curling and accommodation in a gullet and thus are inferior to circular gullet. This form is applied in broaches of standard type used to cut steels and brittle materials (cast iron, bronze etc.)

For cutting steels and other ductile materials by rotor-cut broaches when thick chips are severed, it is recommended to use **circular gullets**.

The **flat-bottomed gullets** are recommended for broaching of deep holes and for ratios $h/t \leq 0.35$.

The gullet surface is polished to facilitate the chip curling and its evacuation from gullets after the broaching is finished.

Rake angle γ of a broach is chosen according to the workpiece material. So, for steels of different machinability the γ=10...20°, for cast-irons with various hardness γ=4...10°, for aluminum and copper γ=12...15°.

Considering that the teeth of the internal broaches are reground only along the face and resharpening decreases their diameter, the roughing teeth clearance angle α=3°, for finishing teeth α=2°, and for sizing teeth α=0...1°. These values of the clearance angles are much smaller than optimal, resulting in reduced tool life.

Another important consideration of the internal broach design is the gullet sizes in terms of **chip accommodation**. This is due to the fact that the chips produced in the process of broaching have no free evacuation. The chip produced in broaching should curl in a roll, which diameter is approximately equal to the tooth height h. Thus, the gullet space necessary and sufficient for chip accommodation is calculated based on the ratio of the gullet volume V_G to the chip volume V_C. This ratio is called the occupation factor:

$$K = V_G / V_C .$$

Considering that the chip widening ratio is close to 1, the calculation of the volume ratio can be simplified to the calculation of the area ratio. Here, as the gullet area F_G is taken only the active gullet area equal to the area of the circle of h diameter, rather than entire gullet space. And the chip area is $F_C = a_z \cdot L_0$, where L_0 is the length of the part hole (Fig. 2.5). Thus:

$$K = V_G / V_C = \pi h^2 / 4 a_z L_0 .$$

Since the chip can not accommodate the entire gullet area, and can not be curled tightly, the permissible value for the ratio K is found experimentally. The poorer is the chip curling the higher is ratio.

For a standard-type broach the K=1.5…4.5, and for a rotor-cut broach, though the chip in this case is thicker, it is advised to adopt the K=2…3, which is due to the fact that no stiffening rib is produced on the chip surface.

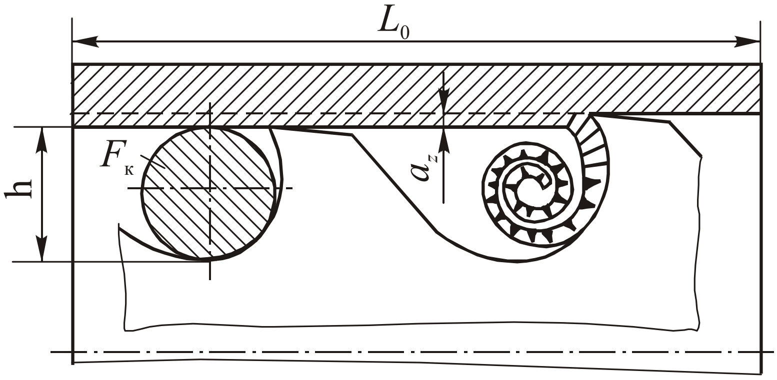


Fig. 2.5 Chip accommodation in a gullet

The length of the broach cutting part and the number of the simultaneously working teeth depends on the teeth pitch and the length of broaching. Moreover, to prevent broach drifting in the hole, the number of simultaneously cutting teeth should be: a) for a standard-type broach – $z_p \geq 2$; b) for a rotor-cut broach – $z_p \geq 3$.

To prevent chatter and tooth marks on the machined surface caused by sharp cutting force fluctuation when the teeth leave the part, it is recommended to make the pitch of the sizing teeth variable with ±0.5 mm deviations.

Accounting to high tensile stresses found in broaching, the **internal broaches are checked for strength**

$$\sigma = P_z / F_{OP} \leq [\sigma],$$

where P_z – is tensile force; F_{OP} – is an area of the weakest section; [σ] – is allowable tensile stress (for solid HSS broaches [σ]=350...400 MPa, for constructional steels [σ]= 250 MPa).

Broach weakest sections include two sections with minimum areas: 1) F_1 – area of the section that runs through the notched pull-end; 2) F_2 – area of the root diameter, measured in a gullet between teeth.

F_1 is found in the tables of GOST 4044-70, and F_2 is calculated as:

$$F_2 = \pi(d_1 - 2h)^2 / 4,$$

where d_1 – is a diameter of the first tooth of a broach.

2.2. Calculation of round rotor-cut broaches

Initial data: workpiece material, hole diameters before and after the broaching, length of broaching, broaching machine model, type of production (App. 4).

Calculation procedure [2]

1. Determine the workpiece material machinability group (Table 2.1) and broached surface finish group (Table 2.2).
2. Select the cutting tool material for the broach (Table 2.3).
3. Choose the construction of the broach. HSS broaches with diameters up to 15 mm, and broaches of all diameters made of tool steels (ХВГ) are made solid, broaches of 15…40 mm in diameter are made welded or assembled. The weld joint is placed at the distance 15…25 mm from the transition cone. Shank material is made of constructional steels (45X or 40X GOST 4543-71). Shank dimensions are according to GOST 4044–70 (Table 2.4). The shank diameter is the nearest smaller to the starting hole diameter before the broaching. The dimensions of the center holes of *B* or *T* type are selected from Table 2.5.
4. Calculate the force permissible by the strength of the pull end:

$$P_{PE} = [\sigma] \cdot F_{OP}, \tag{2.1}$$

where [σ] –the permissible tensile stress, MPa (HSS – [σ]=400 MPa, steels ХВГ and 40X – [σ]=300 MPa); F_{OP} – the an area of the pull end weakest section, mm (Table 2.4).

5. Assign the rake γ and clearance α angles for the broach teeth (Table 2.6).
6. Select the broaching speed (Table 2.7) and compare with the broaching machine pulling speed. If the machine is not capable to provide the calculated value then for the further calculations the speed value from the machine list is adopted.

Table 2.1

Workpiece material machinability groups

Steel		*HB* of the machinability group				
Type	Grade	I	II	III	IV	V
1	2	3	4	5	6	7
free-machining structural GOST1414–75	A12, A20, A30	≤229	–	–	–	–
Quality carbon steel GOST 1050–74	10*, 15*, 20*, 25* 30, 35, 40, 50 60, 70, 80	≤229 ≤255 ≤229	– 255…285 229…255	– 285…321 255…285	– 321…364 285…321	– – 321…364
Alloyed steel GOST 4543–71 Chromium	15X*, 15XA*, 20X*, 30X* 35X*, 30XPA*, 38XA* 40X*, 45X*, 50X*	≤255 ≤229	255…302 229…269	– 269…302	– 302…340	– 340…364
Manganese	15Г*, 20Г*, 25Г*, 30Г*, 33Г 40Г, 45Г, 35Г2, 45Г2, 50Г2	≤241 ≤229	241…269 229…255	269…302 255…285	– 285…321	– 321…364
Manganese (GOST 1050–74)	60Г, 65Г, 70Г		≤241	241…269	269…321	321…340
Chromium-manganese	18XГ*, 20XГP* 18XГT 30XГT, 35XГФ, 40XГTP	≤229 ≤255 ≤229	229…269 255…302 229…269	269…321 302…321 269…302	321…340 – 302…321	340…364 – 321…340
Chromium-silicon	33XC, 38XC, 40XC	–	≤229	229…269	269…302	302…340
Chromium-molybdenum	15XM 30XMA, 35XM	≤229 –	229…269 ≤229	269…302 229…269	302…340 269…321	– 321…340
Chromium-vanadium	15XФ 40XФA	≤229 –	229…269 ≤255	269…302 255…285	302…321 285…321	321…364 321…340

Table 2.1 – continued

1	2	3	4	5	6	7
Chromium-nickel and chromium-nickel-boron	12ХН2*, 12ХН3А*, 12Х2Н4А*, 20ХН*, 20ХНР*, 20ХР3А*, 20Х2Н4А*, 30ХН3А*, 40ХН, 45ХН, 50ХН	≤241	241…269	269…302	302…321	321…364
Chromium-silicon-manganese	20ХГСА, 25ХГСА, 30ХГС, 35ХГСА	–	≤229	229…269	269…321	321…340
Chromium-manganese-nickel and chromium-manganese-nickel with boron and titanium	20ХГНР* 38ХГН 15ХГН2ТА*	≤241 ≤229 ≤229	241…269 229…255 229…269	269…302 255…285 269…302	302…321 285…302 302…321	321…364 302…321 –
Chromium-nickel-molybdenum	25Х2Н4МА, 18Х2Н4МА* 40Х2Н2МА, 38Х2Н2МА 14Х2Н, 3МА*, 20ХН2М 40ХН2МА	– – – –	– ≤229 – –	≤255 229…269 ≤255 ≤269	255…285 269…302 255…269 269…321	285…321 302…340 269…321 321…340
Chromium-nickel-vanadium	20ХН4ФА	–	–	≤255	255…285	285…321
Chromium-aluminum and chromium-aluminum-molybdenum	38Х2Ю, 38Х2МЮА	–	–	≤269	269…302	302…340
Ball bearing GOST 801–60	ШХ15	–	–	–	≤229	–
High speed steel GOST 19265–73	Р18, Р9, Р6АМ5	–	–	–	–	207…255

Table 2.1 – continued

Cast-iron, bronze, copper alloys, aluminum alloys, copper		*HB* of the machinability group				
Type	Grade	VI	VII	VIII	IX	X
1	2	3	4	5	6	7
Gray cast iron GOST 1412–79	СЧ10, СЧ15, СЧ18, СЧ20, СЧ21, СЧ24, СЧ25, СЧ30, СЧ35, СЧ40	≤197	197…285	–	–	–
Malleable cast iron (ferritic) по GOST 1215–79	КЧ30-6, КЧ33-8, КЧ35-10, КЧ37-12	≤163	–	–	–	–
Malleable cast iron GOST 1215–79	КЧ40-3, КЧ45-6, КЧ50-4	≤241	–	–	–	–
Malleable cast iron GOST 1215–79	КЧ50-4	–	≤269	–	–	–
Antifriction malleable cast iron GOST 1585–79	АЧК-1, АЧК-2	187…229	–	–	–	–
Antifriction gray cast iron GOST 1585–79	АЧС-1, АЧС-2, АЧС-3	160…241	–	–	–	–
Tinless bronze (aluminium bronze, silicon bronze) GOST 18175–78	БрА5, БрА7, БрАЖ9-4, БрАЖ9-4, БрАЖН10-4-4, БрАЖМц10-3-1,5, БрАМц9-2, БрКМц3-1, БрКН1-3	–	–	65…140	140…200	–
Tin bronze and leaded tin bronze GOST 5017–74	БрОЦС5-5-5, БрОЦС3-12-5, БрОЦСН3-7-5-1, БрОЦС6-6-3, БрОЦС4-4-17, БрОЦС3,5-6-5, БрОЦС4-4-4-2,5, БрОФ6,5-0,15 БрОФ4-0,25, БрОФ6,5-1,5			≤70 ≤130	130…200	

Table 2.1 – continued

Type	Grade	VI	VII	VIII	IX	X
1	2	3	4	5	6	7
Brass GOST 17711–80	ЛЦ40С, ЛЦ40Сд, ЛЦ40Мц1,5 ЛЦ40Мц3Ж, ЛЦ38Мц2С2, ЛЦ30А3, ЛЦ25С2, ЛЦ23А6Ж3Мц2, ЛЦ16К3, Л63, ЛС59-1, ЛМц58-2, ЛАЖ60-1-1, ЛС62-1				≤165	
Aluminium alloys GOST 4784–74 и GOST 2685–75	АЛ1, АЛ2, АЛ3, АЛ4, АЛ5, АЛ6, АЛ7, АЛ8, АЛ9, АЛ10, АЛ19, АЛ20, АЛ21, Д1, Д6, Д16, Б95, АВ, АК2, АК4, АК6, АК8, АД, АД1, АМг2, АМц, АМг3					50…100
Copper	М1, М2, М3					70…80

* These steels, which carbon content less than 0.25%, regardless of the heat treatment, and steels with carbon content more than 0.25% in annealed condition provide worse surface finish of the machined surface

Table 2.2

Surface finish group of the broached hole

Surface finish group	Requirements	
	Roughness	Accuracy grade
1	$Ra \leq 1.25$	*IT* 5…6
2	$Ra \leq 2.5$	*IT* 7…8
3	$Ra \leq 20$	*IT* 9…10
4	$Ra \geq 20$	*IT* 11 and lower accuracy

Note:
Surface finish group is chosen depending on the most severe requirement (surface finish requirement or accuracy requirement)

Table 2.3

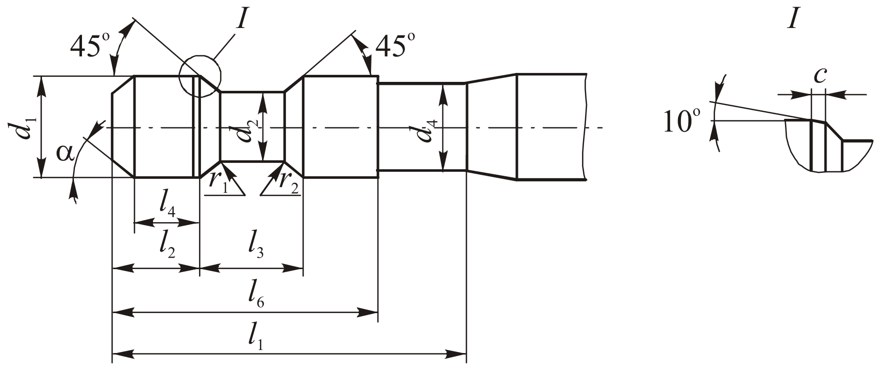
Cutting part material

Machinability group	Production	
	large production run, large-lot production, medium-scale production	small-scale production, single-part production
I-III, VI, VIII-X	Р6АМ5, Р12Ф3, Р6М5	ХВГ
IV, V, VII and difficult-to-machine steels and alloys	Р18, Р12Ф5М, Р9К10, Р6М5К5, Р6ФК8М5	Р18, Р6АМ5, Р12Ф3

Table 2.4

Broach round pull end GOST 4044-70

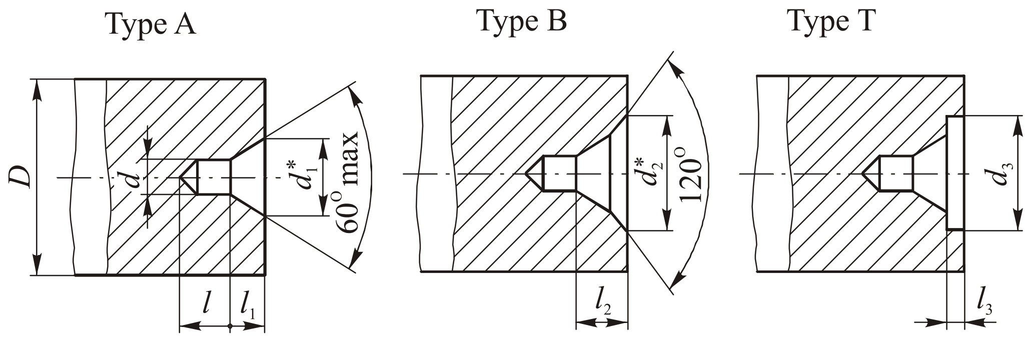
Type 2, Version 1



<table>
<tr><th>dd_1(e8), mm</th><th>d_2(c11), mm</th><th>d, mm</th><th>l_2, mm</th><th>l_3, mm</th><th>l_4, mm</th><th>l_6, mm</th><th>r_1, mm</th><th>r_2, mm</th><th>c, mm</th><th>α, °</th><th>Cross-section area for d_2, mm^2</th></tr>
<tr><td>12</td><td>8.0</td><td>12</td><td rowspan="4">20</td><td rowspan="4">20</td><td rowspan="4">12</td><td rowspan="4">100</td><td>0.2</td><td rowspan="4">0.6</td><td rowspan="7">0.5</td><td>10</td><td>50.3</td></tr>
<tr><td>14</td><td>9.5</td><td>14</td><td rowspan="7">0.3</td><td rowspan="3">20</td><td>70.9</td></tr>
<tr><td>16</td><td>11.0</td><td>16</td><td>95.0</td></tr>
<tr><td>18</td><td>13.0</td><td>18</td><td>132.7</td></tr>
<tr><td>20</td><td>15.0</td><td>20</td><td rowspan="4">25</td><td rowspan="4">25</td><td rowspan="4">16</td><td rowspan="4">120</td><td rowspan="4">1.0</td><td rowspan="15">30</td><td>176.7</td></tr>
<tr><td>22</td><td>17.0</td><td>22</td><td>227.0</td></tr>
<tr><td>25</td><td>19.0</td><td>25</td><td>233.5</td></tr>
<tr><td>28</td><td>22.0</td><td>28</td><td rowspan="2">1.0</td><td>380.1</td></tr>
<tr><td>32</td><td>25.0</td><td>32</td><td rowspan="5">32</td><td rowspan="5">32</td><td rowspan="5">20</td><td rowspan="2">140</td><td rowspan="2">0.4</td><td rowspan="2">1.6</td><td>490.9</td></tr>
<tr><td>36</td><td>28.0</td><td>36</td><td rowspan="7">1.5</td><td>615.7</td></tr>
<tr><td>40</td><td>32.0</td><td>40</td><td rowspan="3">160</td><td rowspan="3">0.5</td><td rowspan="3">2.5</td><td>804.2</td></tr>
<tr><td>45</td><td>34.0</td><td>45</td><td>907.9</td></tr>
<tr><td>50</td><td>38.0</td><td>50</td><td>1134.1</td></tr>
<tr><td>56</td><td>42.0</td><td>56</td><td rowspan="3">40</td><td rowspan="3">40</td><td rowspan="3">25</td><td rowspan="3">190</td><td rowspan="3">0.6</td><td rowspan="3">4.0</td><td>1385.4</td></tr>
<tr><td>63</td><td>48.0</td><td>63</td><td>1809.6</td></tr>
<tr><td>70</td><td>53.0</td><td>70</td><td>2206.4</td></tr>
<tr><td>80</td><td>60.0</td><td>80</td><td rowspan="3">50</td><td rowspan="3">50</td><td rowspan="3">32</td><td rowspan="3">220</td><td rowspan="3">0.8</td><td rowspan="3">6.0</td><td rowspan="3">2.0</td><td>2827.4</td></tr>
<tr><td>90</td><td>70.0</td><td>90</td><td>3848.4</td></tr>
<tr><td>100</td><td>75.0</td><td>100</td><td>4417.9</td></tr>
</table>

Table 2.5

Center holes dimensions GOST 14034-74



* Reference dimension

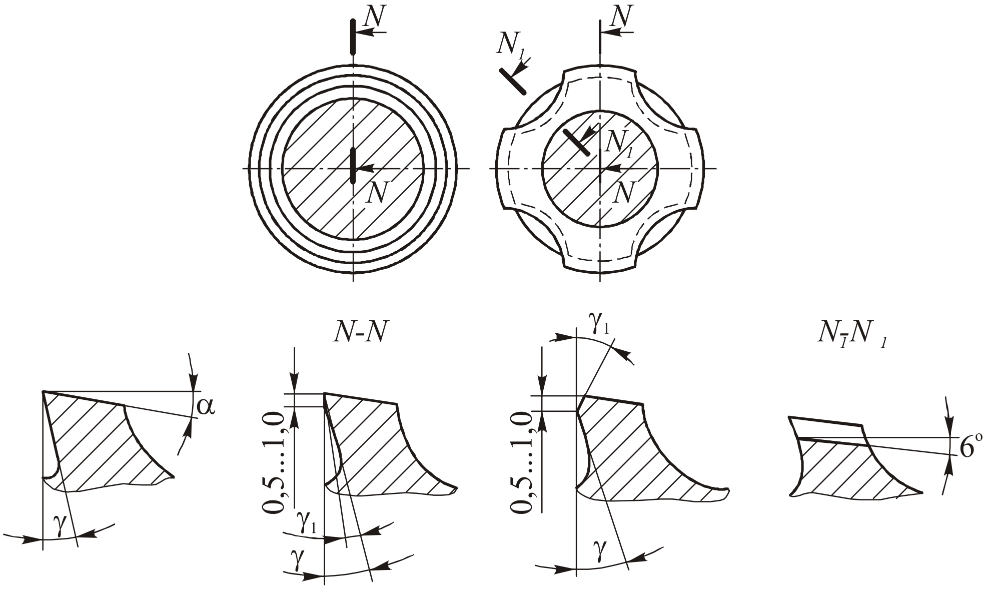
D, mm	*d*, mm	d_1, mm	d_2, mm	d_3, *H*14, mm	*l*, not less than	l_1		l_2, *H*12, mm	l_3, not less than
						Nominal size, mm	Tolerance		
2.0	(0.5)	1.06	–	–	0.8	0.48	H11	–	–
2.5	(0.63)	1.32	–	–	0.9	0.60		–	–
3	(0.8)	1.70	2.50	–	1.1	0.78		1.02	–
4	1.0	2.12	3.15	–	1.3	0.97		1.27	–
5	(1.25)	2.65	4.0	–	1.6	1.21	H12	1.60	–
6	1.6	3.35	5.0	–	2.0	1.52		1.99	–
10	2.0	4.25	6.30	7.0	2.5	1.95		2.54	0.6
14	2.5	5.30	8.0	9.0	3.1	2.42		3.20	0.8
20	3.15	6.70	10.0	12.0	3.9	3.07		4.03	0.9
30	4	8.50	12.50	16.0	5.0	3.90		5.06	1.2
40	(5)	10.60	16.0	20.0	6.3	4.85		6.41	1.6
60	6.3	13.20	18.0	25.0	8.0	5.98		7.36	1.8
80	(8)	17.0	22.40	32.0	10.1	7.79		9.35	2.0
100	10	21.20	28.0	36.0	12.8	9.70		11.66	2.5
120	12	25.40	33.0	–	14.6	11.60		13.80	–
160	16	33.90	42.50	–	19.2	15.50		18.0	–
240	20	42.40	51.60	–	25.0	19.40		22.0	–
360	25	53.00	63.30	–	32.0	24.00		27.0	–

Note:

1. Dimensions given in brackets are not recommended for application.
2. *D* dimensions are recommended values.
3. The length of the taper l_1 can be reduced to $0.5l_1$ if justified.

Table 2.6

Geometrical parameters of cutting part of the round broach



Form A Form B Form C

Broaching conditions	Group of teeth sharpen-ing	Teeth				
		roughing and intermediate		finishing and sizing		
		Form	γ, °	Form	γ, °	γ1, °
Steel of the I machina-bility group and mate-rials of the X machina-bility group	I	A	20*	A	20*	
Steel of the I and II machinability groups	II		15*		18*	
Steel of the IV and V machinability groups	III		10		10	
Malleable cast iron of the VI and VII machin-ability groups	IV		10	B	10	0–5
Grey cast iron of the VI and VII machinabil-ity groups, bronze, brass of the VIII and IX machinability groups	V		10	C	10	-5–0
Teeth	roughing and intermediate		finishing		sizing	
Clearance angle α, °	3		2		1	

* For broaches of 20 mm in diameter can have rake equal to γ=10°.

Table 2.7

Broaching speeds for broaches made of HSS grade P6AM5

Broaches	Type of production	Surface finish group of the broached hole	Cutting speed (m/min) for the following materials							
			Steel					Cast-iron, bronze		Aluminium
			Machinability group							
			I	II	III	IV	V	VI, VIII, IX	VII	X
Round	Large production run, large-lot production, medium-scale production	1	8	8	6	5	3	9	6	4
		2	9	9	8	6	4	12	6	6
		3	13	12	9	8	4	15	9	9
		4	15	13	12	–	–	15	13	12
	Small-scale production, single-part production	1–4	8	6		3		9	6	4

Note:

1. The table below contains the correction coefficients for the broaching speed with relation to cutting tool material:

Cutting tool material	P18	P12Ф5M	P6AM5	P12Ф3	P9K10	P6M5K5	P6Ф2K8M5	ХВГ
Coefficient	1.6		1.0		1.8	2.0		0.7

2. Cutting fluids are selected from Table 2.20.
3. In broaching of ductile steels, marked with an asterisk in Table 2.21, in case of flaws the cutting speed should be reduced by 20–30%.
4. Cutting speeds for broaches of more than 100 mm in diameter can be reduced by 30%.
5. The recommended cutting speeds of Table 2.7 can be increased, provided that the machined surface finish requirements are met.

7. Select the rise per tooth a_{zc} for the roughing teeth depending on the average life of the roughing teeth. For doing this, firstly the average finishing teeth life is chosen from Tables 2.8–2.17 for the adopted cutting speed (Table 2.7) , which is chosen with the finishing teeth RPT being maximum a_{zf}=0.02 mm. Then the RPT for roughing teeth is selected, based on the fact that the roughing and finishing parts have equal tool life that is left to the bold polyline (Table 2.8–2.17).

The selected RPT of the finishing teeth for holes of the 1 and 2 surface finish groups being broached in metals of I, II, III, VI, VII, VIII, IX, X machinability groups are limited according to the recommendations of Table 2.18, to eliminate damage of the machined surface.

In broaching of holes of the other surface finish and machinability groups the average broach life is calculated by the following equation (Table 2.19):

$$T = T_M K_{TB} K_{TP} K_{TW} K_{TM} K_{TD} K_{TO} \text{ (m)},$$

where T_M is the tool life (Tables 2.8 – 2.17); K_{TB} is the coefficient depending on the surface finish group; K_{TP} is the coefficient depending on the cutting scheme; K_{TW} is the coefficient depending on the workpiece type; K_{TM} is the coefficient depending on the cutting part material; K_{TD} is the coefficient depending on the teeth honing; K_{TO} is the coefficient depending on the type of cutting fluid.

8. Then the gullet depth is calculated:

– for continuous chip

$$h = 1.1283\sqrt{K l_s a_{zc}},$$

– for discontinuous chip

$$h = 0.8917\sqrt{K l_s a_{zc}},$$

where K is the occupation factor (K=2.0…3.0); l_s is the broaching length, mm; a_{zc} is the maximum permissible RPT of roughing teeth, mm.

Once the h value is calculated, a nearest greater h value and other gullet dimensions (b, R, r) are selected from Table 2.20.

If the broach core diameter, measured across the gullet bottom, is less than 40 mm, then, to ensure broach strength the gullet depth should be calculated as:

$$h_S = (0.2...0.23)D_0,$$

where D_S is the hole diameter for broaching, mm (if $D_S \leq 20$ mm, the additional 0.2 factor should be used in the equation above).

If $h_s = h_{table}$, then $a_{zo} = a_{zc}$ (a_{z0} is the RPT for roughing teeth), if $h_s < h_{table}$, then the RPT should be reduced:

– for continuous chip

$$a_{z0} = 0.785\frac{h_{sT}^2}{K l_s};$$

– for discontinuous chip

$$a_{z0} = 1.267\frac{h_{sT}^2}{K l_s},$$

where h_{sT} is the gullet depth from Table that is nearest smaller to h.

9. Further, the roughing teeth pitch t_0 is selected (Table 2.20) depending on the gullet depth selected in Appendix 8. The smallest value is taken from a number of pitches provided. The pitch and form of the intermediate teeth are equal to those of the roughing teeth.

The number of simultaneously working teeth is calculated:

$$z_p = \frac{l_{max}}{t_0} + 1 \geq 2...3 .$$

If z_p is an odd number, the fractional part is omitted.

10. Then the maximum permissible pulling force P_{max} is calculated. This force is limited by:

– machine pulling capacity

$$P_M = (0.8...0.9)Q ,$$

where Q is the nominal machine pulling capacity;

– strength of the broach weakest sections:

- strength of the pull end weakest section (refer to Eq. (2.1)),
- strength of the weakest section of the first tooth gullet of the cutting part:

$$P_{OP} = [\sigma]F_{OP} ,$$

where [σ] is the permissible tensile stress, MPa (for HSS broaches [σ]=400 MPa, for tool steels [σ]= 300 MPa); F_{OP} is the area of the weakest section, $F_{OP} = 0.785(D_0 - 2h)^2$.

The smallest of these values is taken as the maximum permissible pulling force P_{max}.

Table 2.8

Average broach life (HSS grades: P9, P18, P6AM5).
Steels of the I machinability group. Broaching with coolant supply

Broaching speed, m/min	Finishing teeth life, m	Roughing teeth life (meters) related to radial RPT of roughing teeth, a_{zc} (mm per tooth)														
		0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.25	0.30	0.35	0.40
1.5	167	462	427	402	383	354	333	317	304	286	265	246	212	188	169	155
2	143	381	352	332	316	292	275	262	251	236	218	203	175	155	140	128
3	115	290	268	253	241	223	210	200	191	180	166	155	133	118	106	97
4	99	239	221	208	198	184	173	165	158	148	137	128	110	97	88	80
5	87	206	191	180	171	162	149	142	136	128	118	110	95	84	76	69
6	79	182	169	159	151	140	132	125	120	113	105	97	84	74	67	61
7	73	164	152	143	136	126	119	113	108	102	94	88	76	67	60	55
8	66	150	139	131	125	115	109	103	99	93	86	80	69	61	55	50
9	64	139	129	121	115	107	100	96	92	86	80	74	64	57	51	47
10	60	129	120	113	107	99	94	89	85	80	74	69	60	53	48	43
11	57	121	112	106	101	93	88	84	80	75	70	65	56	49	45	41
12	54	115	106	100	95	88	83	79	75	71	66	61	53	47	42	39
13	52	109	101	95	90	83	78	75	71	67	62	58	50	44	40	37
14	50	103	96	90	86	79	75	71	68	64	59	55	47	42	38	35
15	48	99	91	86	82	76	72	68	65	61	57	53	45	40	36	33

Table 2.9

Average broach life (HSS grades: P9, P18, P6AM5).
Steels of the II machinability group. Broaching with coolant supply

Broaching speed, m/min	Finishing teeth life, m	Roughing teeth life (meters) related to radial RPT of roughing teeth, a_{zc} (mm per tooth)														
		0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.25	0.30	0.35	0.40
1.5	138	310	287	270	257	238	224	214	205	195	180	168	145	128	116	106
2	118	256	237	223	212	196	185	176	169	161	149	139	119	105	95	87
3	95	195	180	170	162	150	141	134	129	122	113	106	91	80	73	66
4	81	161	149	140	133	124	116	111	106	101	93	87	75	66	60	55
5	72	138	128	121	115	106	100	95	91	87	80	75	65	57	52	47
6	65	123	115	107	102	94	89	84	81	77	71	66	57	51	46	42
7	60	111	104	96	92	85	80	76	73	70	64	60	52	46	41	38
8	56	101	94	88	84	78	73	70	67	64	59	55	47	42	38	34
9	52	93	87	81	77	72	68	64	62	59	54	51	44	39	35	32
10	49	87	81	76	72	67	63	60	58	55	50	47	41	36	32	30
11	47	82	76	71	68	63	59	56	54	51	47	44	38	34	30	28
12	45	77	71	67	64	59	56	53	51	48	45	42	36	32	28	26
13	43	73	67	64	61	56	53	50	48	46	43	40	34	30	27	25
14	41	69	64	61	58	53	50	48	46	44	41	38	32	28	26	24
15	39	66	61	58	55	51	48	46	41	42	39	36	31	27	25	23

Table 2.10

Average broach life (HSS grades: P9, P18, P6AM5).
Steels of the III machinability group. Broaching with coolant supply

Broaching speed, m/min	Finishing teeth life, m	Roughing teeth life (meters) related to radial RPT of roughing teeth, a_{zc} (mm per tooth)										
		0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
1.5	113	226	209	197	187	173	163	155	149	138	127	119
2	97	186	172	162	154	143	135	128	123	114	105	98
3	78	142	131	124	118	109	103	98	94	87	80	75
4	67	117	108	102	97	90	85	81	77	71	66	62
5	59	101	93	88	84	77	73	69	67	62	57	53
6	54	89	83	78	74	68	65	61	59	54	50	47
7	49	80	74	70	67	62	58	55	53	49	45	42
8	46	74	68	64	61	56	53	51	49	45	41	39
9	43	68	63	59	56	52	49	47	45	42	38	36
10	41	63	69	55	52	49	46	44	42	39	36	33
11	39	59	55	52	49	46	43	41	39	36	34	31
12	37	56	52	49	46	43	41	39	37	34	32	29

Table 2.11

Average broach life (HSS grades: P9, P18, P6AM5).
Steels of the IV machinability group. Broaching with coolant supply

Broaching speed, m/min	Finishing teeth life, m	Roughing teeth life (meters) related to radial RPT of roughing teeth, a_{zc} (mm per tooth)							
		0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.15
0.7	152	268	242	223	209	189	174	163	151
1	120	202	183	169	158	143	132	123	114
1.5	91	147	133	123	115	104	96	90	83
2	75	117	106	98	92	83	76	72	66
2.5	66	99	89	82	77	69	64	60	56
3	57	85	77	71	67	60	56	52	48
3.5	52	76	68	63	59	53	49	46	42
4	47	68	61	57	53	48	44	42	38
4.5	44	62	56	52	49	44	40	38	35
5	41	57	52	48	45	40	37	35	32
5.5	38	53	48	44	41	37	34	32	30
6	36	50	44	41	38	35	32	30	28

Table 2.12

Average broach life (HSS grades: P9, P18, P6AM5).
Steels of the V machinability group. Broaching with coolant supply

Broaching speed, m/min	Finishing teeth life, m	Roughing teeth life (meters) related to radial RPT of roughing teeth, a_{zc} (mm per tooth)									
		0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.12	0.15
0.7	74	100	91	84	78	74	71	68	65	61	62
1	59	76	68	63	59	56	53	51	49	46	39
1.5	45	55	50	46	43	41	39	37	36	34	29
2	37	44	40	37	34	32	31	30	29	27	23
2.5	32	37	33	31	29	27	26	25	24	23	19
3	28	32	29	27	25	24	23	22	21	20	17
3.5	25	28	26	24	22	21	20	19	18	17	15
4	23	26	23	21	20	19	18	17	17	15	13
4.5	22	23	21	19	18	17	16	16	16	14	12
5	20	21	19	18	17	16	15	14	14	13	11
5.5	19	20	18	17	16	15	14	13	13	12	10
6	18	18	17	15	14	14	13	12	12	11	9
7	16	16	15	14	13	12	12	11	11	10	8
8	15	15	13	12	12	11	10	10	10	9	8

Table 2.13

Average broach life (HSS grades: P9, P18, P6AM5).
Cast-irons of the VI machinability group

Broaching speed, m/min	Finishing teeth life, m	Roughing teeth life (meters) related to radial RPT of roughing teeth, a_{zc} (mm per tooth)														
		0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.25	0.30	0.35	0.40
2	101	339	317	301	289	270	257	247	238	228	216	205	185	170	158	148
3	132	265	248	235	226	211	201	192	186	178	168	160	144	132	123	116
4	115	222	208	198	189	177	168	161	156	149	141	135	121	111	104	97
5	103	194	181	172	165	155	147	141	136	130	123	117	106	97	90	85
6	94	174	162	154	148	138	131	126	122	117	110	105	95	87	81	76
7	87	158	148	140	135	126	120	115	111	106	100	96	86	79	73	69
8	82	146	136	129	124	116	110	106	102	98	93	88	79	73	68	64
9	77	136	127	120	115	108	103	98	95	91	86	82	74	68	63	59
10	73	127	119	113	108	101	97	92	89	85	81	77	69	64	59	56
11	70	120	112	106	102	95	81	87	84	80	76	73	65	60	56	52
12	67	114	106	101	97	91	86	83	80	76	72	69	62	57	53	50
13	64	108	101	96	92	86	82	79	76	73	69	66	59	54	50	47
14	62	103	97	62	88	83	78	75	73	70	60	63	56	52	48	45
15	60	99	93	86	85	79	75	72	70	67	63	60	54	50	46	43

Table 2.14

Average broach life (HSS grades: P9, P18, P6AM5).
Cast-irons of the VII machinability group

Broaching speed, m/min	Finishing teeth life, m	Roughing teeth life (meters) related to radial RPT of roughing teeth, a_{zc} (mm per tooth)														
		0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.25	0.30	0.35	0.40
2	99	195	183	174	166	156	148	142	137	134	126	120	108	99	82	87
3	81	158	143	136	130	122	116	111	107	104	99	94	84	77	72	68
4	71	128	120	114	109	102	97	92	90	87	83	79	71	65	60	57
5	63	112	105	99	95	89	85	81	78	76	72	69	62	57	53	50
6	58	100	93	89	85	80	76	73	70	68	65	61	55	51	47	44
7	54	91	85	81	78	73	69	66	64	62	59	56	50	46	43	40
8	50	84	78	75	71	67	64	61	59	57	54	52	46	43	40	37
9	47	78	73	69	66	62	59	57	55	53	50	48	43	40	37	35
10	45	73	68	65	62	58	55	53	51	50	47	45	40	37	35	32
11	43	69	64	61	59	55	52	50	48	47	44	42	38	35	33	31
12	41	65	61	58	56	52	49	47	46	45	42	40	36	33	31	29
13	39	62	58	55	53	50	47	45	44	43	40	38	34	31	29	27
14	38	59	56	53	51	48	45	43	42	41	38	36	33	30	28	26
15	37	57	54	51	49	46	43	41	40	39	37	35	32	29	27	25

Table 2.15

Average broach life (HSS grades: P9, P18, P6AM5).
Bronzes of the VIII machinability group. Broaching with coolant supply

Broaching speed, m/min	Finishing teeth life, m	Roughing teeth life (meters) related to radial RPT of roughing teeth, a_{zc} (mm per tooth)														
		0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.25	0.30	0.35	0.40
2	510	1033	967	919	881	825	783	751	725	687	650	618	557	511	475	446
3	418	807	755	717	688	644	612	586	566	536	507	483	435	399	371	349
4	363	677	634	602	577	540	513	492	475	450	426	405	365	335	311	292
5	326	591	553	525	504	472	448	430	415	393	372	354	318	292	272	255
6	298	529	495	470	451	422	401	384	371	351	332	316	285	262	243	228
7	276	481	450	428	410	384	365	350	338	320	303	288	259	238	221	208
8	259	444	415	394	378	354	336	322	311	295	279	266	239	219	204	192
9	244	413	386	367	352	329	313	300	290	274	260	247	222	204	190	178
10	232	387	362	344	330	309	294	281	272	257	244	232	209	192	178	167
11	221	365	342	325	311	292	277	265	256	243	230	219	197	181	168	158
12	212	346	324	308	259	276	263	252	243	230	218	207	187	171	159	150
13	204	330	309	293	281	263	250	240	231	219	207	197	178	163	152	142
14	197	315	295	280	269	252	239	229	221	210	198	189	170	156	145	136
15	190	302	283	269	258	241	229	220	212	201	190	181	163	150	139	131

Table 2.16

Average broach life (HSS grades: P9, P18, P6AM5).
Bronzes of the IX machinability group. Broaching with coolant supply

Broaching speed, m/min	Finishing teeth life, m	Roughing teeth life (meters) related to radial RPT of roughing teeth, a_{zc} (mm per tooth)														
		0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.25	0.30	0.35	0.40
2	261	497	465	442	424	397	377	361	349	332	314	299	269	247	230	216
3	214	288	363	345	331	310	294	282	273	259	245	233	210	193	179	168
4	186	326	305	290	278	260	247	236	229	217	206	196	176	162	150	141
5	167	284	266	253	242	227	217	207	200	190	180	171	154	141	131	123
6	152	254	238	226	217	203	193	185	179	170	161	153	138	126	118	110
7	141	232	217	206	197	185	176	168	162	155	146	139	125	115	107	100
8	132	213	200	190	182	170	162	155	150	142	135	128	115	106	99	93
9	125	199	186	177	169	158	151	144	139	133	125	119	108	99	92	86
10	118	186	174	166	159	149	141	135	131	124	118	112	101	93	86	81
11	113	176	164	156	150	140	133	128	123	117	111	106	95	87	81	76
12	108	167	156	148	142	133	126	121	117	111	105	100	90	83	77	72
13	104	159	149	141	135	127	120	115	111	106	100	95	86	79	73	69
14	100	152	142	135	129	121	115	110	106	101	96	91	82	75	70	66
15	97	145	136	129	124	116	110	106	102	97	92	87	79	72	67	63

Table 2.17

Average broach life (HSS grades: P9, P18, P6AM5).
Aluminium of the X machinability group. Broaching with coolant supply

Broaching speed, m/min	Finishing teeth life, m	Roughing teeth life (m) for a given radial RPT of roughing teeth a_{zc}, mm per tooth										
		0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.15	0.16	0.20
1	294	626	594	570	551	523	503	486	473	461	452	443
1.5	257	508	482	463	448	425	408	394	384	375	366	359
2	234	438	415	399	386	366	352	340	331	323	315	310
2.5	217	389	370	356	344	326	314	303	295	283	282	278
3	204	355	336	324	313	297	285	276	268	262	256	252
3.5	194	328	311	300	289	274	264	255	248	242	237	232
4	185	306	291	279	270	257	246	238	231	226	221	217
4.5	178	288	274	263	254	242	232	224	218	213	208	204
5	172	274	259	249	241	228	219	212	206	201	197	193
5.5	167	260	247	237	229	217	209	202	196	192	188	184
6	162	249	236	226	219	208	200	193	188	183	179	176
7	154	228	218	209	202	192	184	178	173	169	166	163
8	147	214	203	195	189	179	172	167	162	158	155	152
9	141	202	191	184	178	169	162	157	152	149	146	143
10	137	191	181	174	168	160	154	148	144	141	138	136

Table 2.18

Recommended radial RPT for roughing teeth a_{zc}, mm per tooth

Broaching speed v, m/min	Machinability group													
	I		II		III		VI		VII, VIII		IX		X	
	Surface finish group													
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
To 3	0.18	0.23	0.14	0.18	0.12	0.15	0.16	0.20	0.14	0.18	0.12	0.16	0.15	0.20
Over 3 to 6	0.14	0.19	0.12	0.15	0.10	0.12	0.13	0.17	0.11	0.15	0.10	0.13	0.12	0.17
Over 6 to 10	0.12	0.15	0.10	0.12	0.08	0.10	0.10	0.14	0.09	0.12	0.08	0.10	0.10	0.14
Over 10 to 15	0.10	0.12	0.08	0.10	0.06	0.08	0.08	0.12	0.07	0.10	0.06	0.08	0.08	0.12

Note:
1. The RPT for broaching of steels of the IV and V machinability groups are selected from Tables 2.11 and 2.12.
2. The RPT for the 3rd and 4th surface finish groups are selected from Tables 2.8 – 2.17.

Table 2.19

Broach life correction coefficients for different broaching conditions.
a) depending on the type and required surface finish of the broached surface

Regrinding	Surface being broached	K_{TB} for the group of surface finish			
		1	2	3	4
On the rake surface	Cylindrical holes	0.7	1.0	1.5	2.0

Table 2.19 – continued

b) depending on the type of broaching

Type of broaching	Rotor-cut and trapezoid	Standard (with narrow notches)	Spline broach with staggered notches
K_{TP}	1.0	0.5	0.7

c) depending on the workpiece type and surface conditions of the starter hole

Workpiece	K_{TW} for surfaces that		
	machined	nonmachined	
		etched	nonetched
Rolled, stamped, forged	1.0	1.0	0.8
Cast:			
steel	0.9	0.7	
cast-iron	1.0	0.7	
nonferrous metals	1.0		

d) depending on the broach material

Broach material	Р12Ф5М	Р6АМ5, Р12Ф3	Р9К10	Р6М5К5, Р6Ф2К8М5	ХВГ
K_{TM}	1.1	1.0	1.3	1.5	0.5

e) depending on the teeth honing

Teeth	Honed	Nonhoned
K_{TD}	1.0	0.75

Table 2.19 – continued

f) depending on the type of cutting fluid used

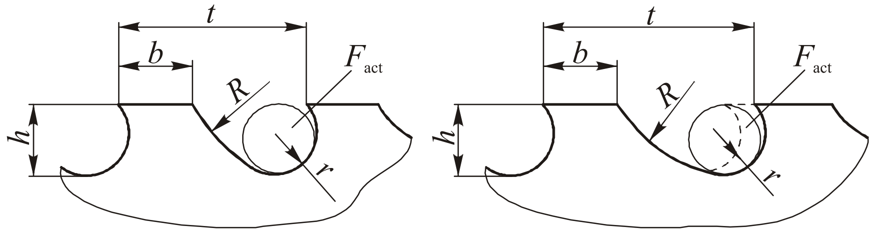
Workpiece material		K_{TO} for cutting fluids							
		A	B	C	D	E	F	G	H
Steels	Structural carbon	1.0	1.3	0.8	0.8	0.8	1.0	–	1.0
	Structural alloyed	1.0	1.3	0.8	0.8	–	1.0	0.9	1.0
Cast-irons	Gray, malleable	–	–	–	–	–	1.0	0.9	1.0
	Antifriction	–	–	–	–	–	–	–	1.0
Bronzes, brasses		1.0	1.0	1.0	1.0	1.0	–	–	1.2
Aluminium alloys		1.0	1.0	1.0	1.0	1.0	–	–	–

Note:
1. For dry broaching of aluminium alloys the K_{TO} =0.8.
2. Explanation of cutting fluids designation: A – 3-10% emulsion of «Укринол-1»; B – 5% emulsion of СДМУ-2; C – 5% emulsion of Э-2 (ЭТ-2, ЭГТ); D – 10% emulsion of Э-2; E – 5-7% emulsion of T; F – ОСМ-3 oil; G – И-12А , ГИ-20А industrial oils; H – MP-3 cutting fluid.
3. Grey and malleable cast-irons, bronze, brass and aluminium alloys allow dry broaching.

Table 2.20

Teeth profiles according to Appendix 2 of GOST 20365–74

Profile with elongated gullet (E)



Dimensions, mm					F_{act}, mm^2	Profile number
t	h	r	b	R		
1	2	3	4	5	6	7
4.0	1.6	0.8	1.5	2.5	1.77	1
	1.8	0.9	1.2	2.8	2.54	2
4.5	1.6	0.8	2.0	2.5	1.77	1
	1.8	0.9	1.7	2.8	2.54	2
	2.0	1.0	1.5	3.0	3.14	3
5.0	1.6	0.8	2.2	2.5	1.77	1E
	1.8	0.9		2.8	2.54	2
	2.0	1.0	2.0	3.0	3.14	3
5.5	1.6	0.8	2.5	2.5	1.77	1E
	1.8	0.9	2.7	2.8	2.54	2
	2.0	1.0	2.5	3.0	3.14	3
6.0	1.8	0.9	2.7	2.8	2.54	2E
	2.0	1.0	3.0	3.0	3.14	3
	2.5	1.3	2.0	4.0	4.00	4
7.0	2.0	1.0	3.5	3.0	3.14	3E
	2.5	1.3	3.0	4.0	4.90	4
	3.0	1.5	2.3	5.0	7.10	5
8.0	2.5	1.3	4.0	4.0	4.9	4
	3.0	1.5	3.3	5.0	7.1	5
	3.6	1.8	2.5	5.5	9.6	6
9.0	2.5	1.3	4.0	4.0	4.9	4E
	3.0	1.5	4.3	5.0	7.1	5
	3.6	1.8	3.5	5.5	9.6	6
10	3.0	1.5	4.3	5.0	7.1	5E
	3.6	1.8	4.5	5.5	9.6	6
	4.0	2.0	3.5	6.0	12.6	7
11	3.6	1.8	4.5	5.5	9.6	6E
	4.0	2.0		6.0	12.6	7
	4.5	2.3	4.0	7.0	15.9	8

Table 2.20 – continued

1	2	3	4	5	6	7
12	4.0	2.0	5.5	6.0	12.6	7
	4.5	2.3	5.0	7.0	15.9	8
	5.0	2.5	4.0	8.0	19.6	9
13	4.0	2.0	5.5	6.0	12.6	7E
	4.5	2.3	6.0	7.0	15.9	8
	5.0	2.5	5.0	8.0	19.9	9
14	4.5	2.3		7	15.9	8E
	5.0	2.5	6.0	8	19.6	9
	6.0	3.0	4.5	10	28.3	10
15	4.5	2.3	6.0	7	15.9	8E
	5.0	2.5	7.0	8	19.6	9
	6.0	3.0	5.5	10	28.3	10
16	5.0	2.5	7.0	8	19.6	9E
	6.0	3.0	6.5	10	28.3	10
	7.0	3.5	5.0	11	38.5	11
17	5.0	2.5	7.0	8	19.6	9E
	6.0	3.0	7.5	10	28.3	10
	7.0	3.5	6.0	11	38.5	11
18	6.0	3.0	8.5	10	28.3	10
	7.0	3.5	7.0	11	38.5	11
	8.0	4.0	6.0	12	50.3	12
19	6.0	3.0	8.5	10	28.3	10E
	7.0	3.5	8.0	11	38.5	11
	8.0	4.0	7.0	12	50.3	12
20	7.0	3.5	9.0	11	38.5	11
	8.0	4.0	8.0	12	50.3	12
	9.0	4.5	6.0	14	63.3	13
21	7.0	3.5	9.0	11	38.5	11E
	8.0	4.0		12	50.3	12
	9.0	4.5	7.0	14	63.6	13
22	7	3.5		11	38.5	11E
	8	4.0	9.0	12	50.3	12E
	9	4.5	8.0	14	63.6	13
24	8	4.0	9.0	12	50.3	12E
	9	4.5	10.0	14	63.6	13
	10	5.0	8.5	16	78.5	14
25	8	4.0	10.0	12	50.3	12E
	9	4.5	9.5	14	63.6	13E
	10	5.0	9.5	16	78.5	14
26	8	4.0	10.5	12	50.3	12E
	9	4.5	10.0	14	63.6	13E
	10	5.0	10.5	16	78.5	14

Table 2.20 – continued

1	2	3	4	5	6	7
28	9	4.5	10.0	14	63.6	13E
	10	5.0	10.5	16	78.5	14E
	12	6.0	9.5	20	113.1	15
30	9	4.5		14	63.6	13E
	10	5.0	12.0	16	78.5	14E
	12	6.0	11.5	20	113.1	15
32	9	4.5		14	63.6	13E
	10	5.0	12.0	16	78.5	14E
	12	6.0		20	113.1	15E

Note:
1. Elongated profiles ”E” are produced with the same cutter, but with additional travel.
2. Elongated profiles ”E” can be produced with pitches different from those given in the table.
3. Pitches of finishing and sizing teeth (t_1, t_2, t_3) are unequal and are established according to the drawing and Table 2.25.

11. Further, the number of teeth in a row is calculated (must be from 2 to 5)

$$z_C = \frac{\pi D q_o z_P K_{Pm} K_{Po} K_{Pk} K_{Pp}}{P_{max}},$$

where D is the diameter of the broached hole; q_o is the specific pulling force, N/mm (Table 2.21); z_p is the number of simultaneously working teeth; K_{Pm}, K_{Po}, K_{Pk}, K_{Pr} – correction coefficients (Table 2.22); P_{max} is the maximum permissible pulling force.

If z_C<2, then the calculations are made for z_C=2. If z_C>2 or is fractional, it is rounded to nearest larger number – 3, 4 or 5.

If z_C>5, then the specific pulling force is calculated for z_C=5

$$q_o = \frac{z_C P_{max}}{\pi D z_P K_{Pm} K_{Po} K_{Pk} K_{Pp}}.$$

Further, the new value of RPT is taken from Table 2.21 according to the q_o value that is the nearest smaller to the calculated value.

Table 2.21

Specific pulling force q_0 (N) per 1 mm of the cutting edge length in broaching of structural carbon steels and alloy steels in normalized, annealed and hot-rolled condition. Cutting fluid: MP-3

RPT a_z. mm	Rake angle γ . degrees				
	5	10	15	20	25
1	2	3	4	5	6
0.01	78	48	37	30	26
0.015	91	60	47	39	34
0.02	100	70	56	48	43
0.025	113	80	66	57	51
0.03	124	91	76	67	60
0.035	136	101	85	75	69
0.04	148	112	95	84	77
0.045	160	122	105	93	86
0.05	171	132	114	103	95
0.06	195	153	134	121	112
0.07	218	174	153	139	130
0.08	241	195	172	157	146
0.09	264	216	191	176	165
0.10	289	236	212	194	181
0.11	311	258	230	212	200
0.12	334	277	249	232	217
0.13	358	298	269	250	237
0.14	380	320	288	268	253
0.15	403	338	312	286	271
0.16	425	360	327	304	291
0.17	446	381	346	325	308
0.18	468	402	365	343	325
0.19	492	419	385	362	342
0.20	513	433	404	380	364
0.21	533	462	423	398	381
0.22	558	483	443	416	398
0.23	578	504	462	434	416
0.24	602	525	481	453	433
0.25	626	541	501	471	451
0.26	645	562	520	494	468
0.27	669	583	539	512	491
0.28	693	604	559	531	508
0.29	711	624	579	549	526
0.30	735	645	597	567	544
0.31	752	666	617	586	561
0.32	776	687	628	604	579

Table 2.21 – continued

1	2	3	4	5	6
0.33	800	708	655	623	596
0.34	823	722	675	641	614
0.35	840	743	694	659	631
0.36	863	763	713	678	649
0.37	887	784	733	696	667
0.38	910	805	752	714	684
0.39	933	825	771	733	702
0.40	957	846	791	751	719

12. Then, the pulling force is calculated as:

$$P = \frac{\pi D q_o z_P K_{Pm} K_{Po} K_{Pk} K_{Pp}}{z_C}.$$

13. The diametric allowance for broaching is:

$$A = D_{max} - D_{0_{min}},$$

where D_{max} is the maximum limit of size of the broached hole, mm; D_{0min} is the minimum limit of size of the starter hole for broaching, mm.

Thus the allowance for roughing teeth is:

$$A_0 = A - (A_I + A_F),$$

where A_I is the allowance for intermediate teeth, mm (Table 2.23); A_F is the allowance for finishing teeth, mm (Table 2.24).

14. The number of rows of roughing teeth is determined as:

$$i_0 = \frac{A_0}{2a_{z_0}}.$$

If the i_0 value is fractional, it is rounded to the nearest smaller integer. Then the remainder of the roughing allowance is calculated as:

$$A_{remainder} = A_0 - 2a_{z_0} i_0.$$

Depending on the value of the roughing allowance remainder, it is:

a) added to the roughing allowance in the form of an additional row, if the $\frac{1}{2}A_{remainder}$ is bigger than the RPT of the first row of intermediate part (Table 2.23);

b) added to the intermediate part, if the $\frac{1}{2}A_{remainder}$ is bigger than the RPT of the first row of intermediate part, but not smaller than 0.02…0.03 mm;

c) added to the finishing part in the form of additional teeth, if the $\frac{1}{2}A_{remainder}$ is smaller than 0.02…0.03 mm (refer to Table 2.24).

15. The number of roughing teeth is determined by the equation:

$$z_0 = i_0 z_{c_0},$$

where i_0 is the refined number of roughing rows, obtained after distributing the remaining allowance. Then the total number of the broach teeth is:

$$\sum z = z_0 + z_{\text{I}} + z_{\text{F}} + z_{\text{S}}.$$

16. The length of the broach cutting part is calculated as:

$$L_C = l_0 + l_{\text{I}} + l_{\text{F}} + l_{\text{S}} = t_0 (z_0 + z_{\text{I}}) + \sum t_{\text{F}} + \sum t_{\text{S}},$$

Where Σt_{F}, Σt_{S} are the sums of varied pitches of the finishing and sizing teeth respectively.

The pitches of the finishing and sizing teeth are variable and represent a set of three values. The smaller pitch t_1 is selected from Table 2.25 depending on the roughing teeth pitch t_0. Values for the middle pitch t_2 and greater pitch t_3 are selected from the same table. The first pitch of the finishing part (between the first and the second teeth) has the greater value – t_3.

The profile of gullet is equal for all the three pitches. The profile is selected from Table 2.20 according to the smaller pitch t_1 and average profile depth.

Further, a table with teeth diameters is composed.

17. Then the diameter of the sizing teeth D_{S} and diameter of the last finishing tooth are set equal to the maximum limit of size of the broached hole. Tolerances for the teeth manufacture are according to GOST 9126-76.

Table 2.22

Correction coefficients for specific pulling force related to the broaching conditions

a) depending on hardness and conditions of the workpiece material

Workpiece materials		Hardness, *HB*	Coefficient K_{PM}
Steels of the I-V machinability groups	hardened	<285	1.3
		285…336	1.3
		336…375	1.4
	Annealed, normalized and hot-rolled	130…321	1.0
Tool steels, alloyed steels and HSS		204…229	1.4
Grey, malleable and antifriction cast-irons of the VI and VII machinability groups		<229	0.5
		≥229	0.7
Bronzes and brasses VIII and IX machinability groups		≤110	0.4
Aluminium alloys of the X machinability group		≤110	0.4

b) depending on the type of cutting fluid

Workpiece materials	Cutting fluid	K_{Po}
Steel	B, K	0.8
	A, F, G, H	1.0
	C, D, E	1.1
Cast-iron	No cooling	1.0
	F, G, H	0.8

c) depending on the surface finish group

Surface finish group	1.2	3.0	4.0
K_{Pk}	1.0	1.1	1.2

d) depending on the type of chip breaking

Chip breaking method	K_{Pp}
Fillets or slots	1.0
Narrow notches	1.2
No chip breakers	1.3

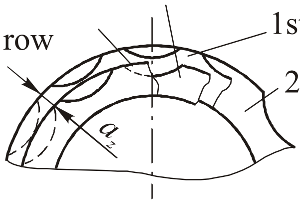
Table 2.23

RPT in intermediate rows, diametric allowance for intermediate part and number of intermediate teeth

Radial RPT of roughing teeth a_{z0}, mm	Number of teeth in a row of the intermediate part	Radial RPT a_{zI} (mm) for a row of teeth in intermediate part				Diametric allowance A_I, mm	Number of intermediate teeth z_I
		first row	second row	third row	fourth row		
To 0.03	2–3	–	–	–	–	–	–
	4–5	–	–	–	–	–	–
0.04…0.06	2–3	0.02	–	–	–	0.04	2
	4–5	–	–	–	–	–	–
0.07…0.10	2–3	0.04	0.03	–	–	0.14	4
	4–5	0.02	–	–	–	0.04	2
0.11…0.15	2–3	0.05	0.03	–	–	0.16	4
	4–5	0.03	–	–	–	0.06	2
0.16…0.20	2–3	0.08	0.06	0.03	–	0.34	6
	4–5	0.05	0.03		–	0.16	4
0.21…0.25	2–3	0.11	0.09	0.06	0.03	0.58	8
	4–5	0.07	0.05	0.03	–	0.30	6
0.25…0.30	2–3	0.14	0.09	0.06	0.03	0.64	8
	4–5	0.09	0.06	0.03	–	0.36	6
0.30…0.40	2–3	0.17	0.12	0.06	0.03	0.76	8
	4–5	0.11	0.06	0.03	–	0.40	6

Table 2.24

RPT for finishing teeth, allowance, number of finishing and sizing teeth

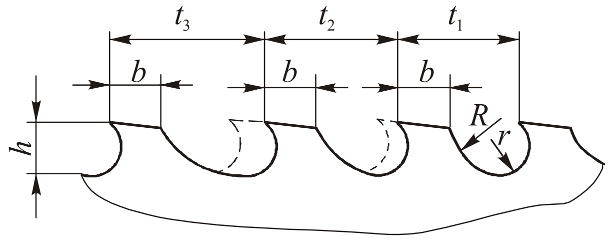


Rise per row
(Row consists of two teeth equal in diameter)

Surface finish group	Number of rows (two teeth) for a given a_{zF}, mm			Total number of finishing teeth z_F	Diametric allowance A_F, mm	Number of sizing teeth z_S
	0.02	0.01	0.005			
1	2	2	2	12	0.14	7
2	1	2	2	10	0.10	6
3	1	2	–	6	0.08	5
4	1	1	–	4	0.06	4

Table 2.25

Pitches of finishing and sizing teeth



t_0, mm	t_3, mm	t_2, mm	t_1, mm	t_0, mm	t_3, mm	t_2, mm	t_1, mm
4.0	t_1+1 mm	t_1+0.5 mm	4.0	15	t_1+2 mm	t_1+1 mm	11
4.5			4.0	16			11
5.0			4.0	17			12
5.5			4.0	18			13
6.0			4.5	19			14
6.5			5.0	20			14
7.0			5.5	21			15
8.0			6.0	22			16
9.0	t_1+2 mm	t_1+1 mm	6.0	24			17
10.0			7.0	25			18
11.0			7.0	26			19
12.0			8.0	28			20
13.0			9.0	30	t_1+4 mm	t_1+2 mm	20
14.0			10.0	32			22

Note: The dimensions h_1, b_1, R_1 and r_1 of the finishing and sizing teeth profile are the same for all three pitches and are set relatively to the pitch t_1.

18. Then number, width (Table 2.26) and radius R_W (Table 2.28) of the roughing teeth fillets are selected.

19. Number of fillets for intermediate and finishing teeth is calculated (rounding to the nearest integer) by the equation:

$$N_R = 1.45\sqrt{D},$$

where D is the diameter of the broach, mm.

Width of the fillets for these teeth is selected from Table 2.27, and fillet radius is according to Table 2.28.

20. The diameter of the front pilot is set equal to the minimum limit of size of the starter hole for broaching, and the tolerance of the front pilot is $e8$. Length of the front pilot is determined by the ratio of the

length of cut to the diameter of the broach: if l/D>1.5, then l_{FP}=0.75l; if l/D<1.5, then l_{FP}=l.

21. Then the length of the transition cone is selected (Table 2.29).

22. The distance form the front end of the broach to the first tooth (Fig. 2.6) is calculated as:

$$L_1 = l_1 + l_2 + l_3 + l + 25 \text{ mm}.$$

The length l_1 is relative to the pull end diameter:

D_{PE}, mm	12…20	22…28	32…50	55…70
l_1, mm	115	150	160	205

Depending on the broaching machine l_2≈25 mm, and l_3≈50 mm.

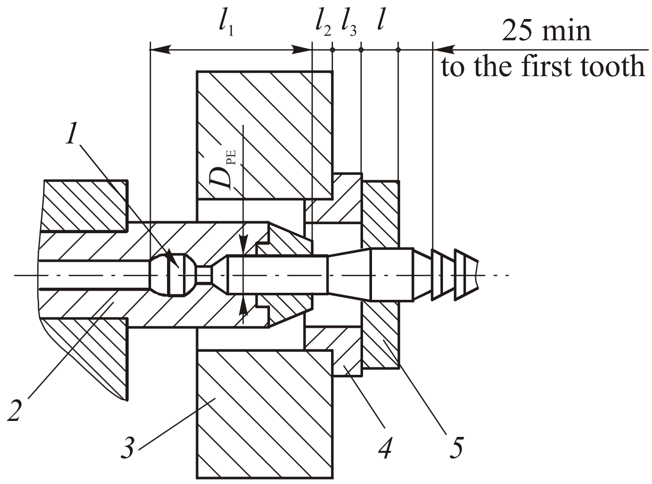
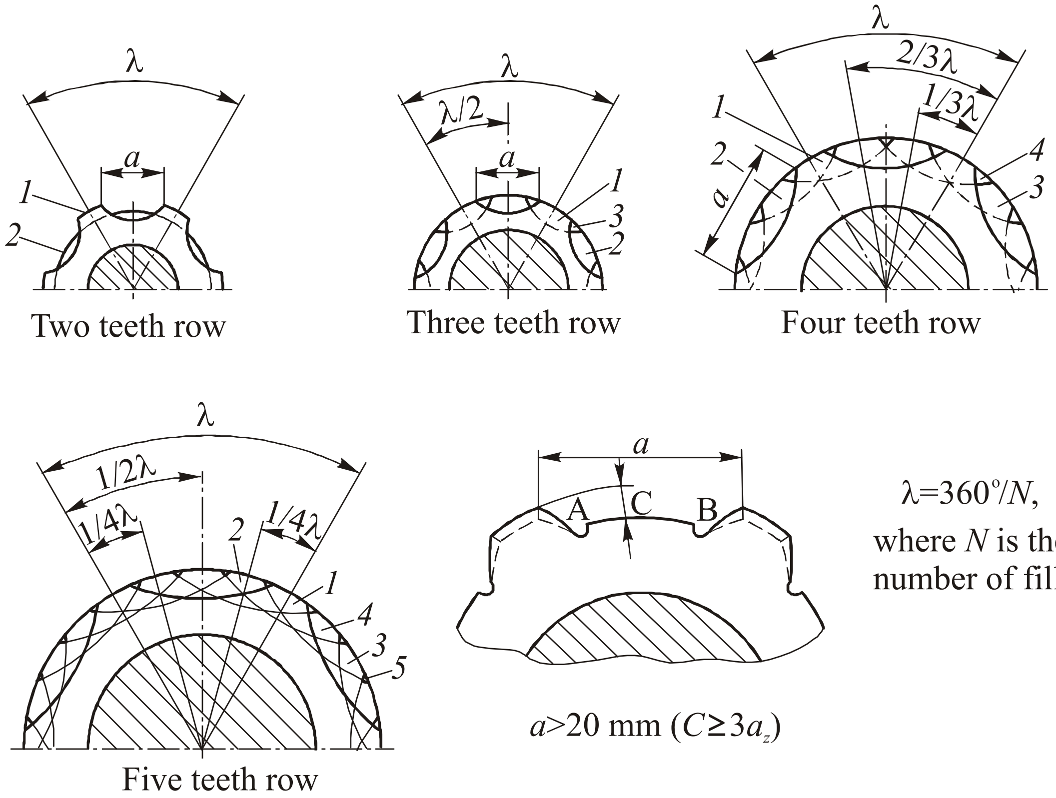


Fig. 2.6 Schematic for calculation distance from the front end to the first tooth of the broach: 1 – pull end; 2 – pull head; 3 – faceplate; 4 – adaptor; 5 – workpiece

23. The diameter of the rear pilot D_{RP} is set equal to the minimum limit of size of the broached hole, and tolerance is $f7$. Length of the rear pilot l_{RP} is selected from Table 2.30, and length and dimensions of the retriever are according to Table 2.6.

Table 2.26

Number and dimensions (mm) of fillets of the roughing teeth of round broaches



$\lambda = 360°/N$,
where N is the number of fillets

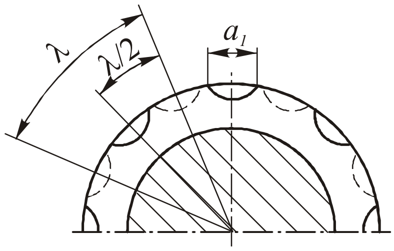
Teeth diameter, mm	z_C=2		z_C=3		Teeth diameter, mm	z_C=2		z_C=3	
	N	a_K	N	a_K		N	a_K	N	a_K
1	2	3	4	5	1	2	3	4	5
6…7	4	2.5	–	–	40…42	10	6.5	6	14.0
7…8		3.0			42…45		7.0		15.0
8…9		3.5			45…48		7.5		16.0
9…10		4.0			48…50		7.5		17.0
10…11		4.5			50…52		8.0		18.0
11…12		5.0			52…55		8.5		19.0
12…13		5.5			55…60	12	7.5	8	15.0
14…15		6.0			60…63		8.0		16.0
15…16	6	4.0	4	8.0	63…65		8.5		17.0
16…17		4.5		8.5	65…70		9.0		18.0
17…18		5.0		9.0	70…75		9.5		19.0
18…19		5.0		9.5	75…80	14	9.0		20.0
19…20		5.0		10.0	80…85		9.5		21.0
20…22		5.5		11.0	85…90		10.0		22.0
22…24		6.0		12.0	90…95		10.5		24.0
24…25		6.5		13.0	95…100		11.0		25.0

Table 2.26 – continued

1	2	3	4	5	1	2	3	4	5
25…26	8	5.0	6	9.0	100…105	16	10.0	10	21.0
26…28		5.5		9.5	105…110		11.0		22.0
28…30		6.0		10.0	110…120		11.5		24.0
30…32		6.0		11.0	120…125		12.0		26.0
32…34		6.5		11.5	125…130		12.0		26.0
34…36		7.0		12.0	130…140		13.0		28.0
36…38		7.5		13.0					
38…40		7.5		13.0					

Table 2.27

Number and dimensions (mm) of the fillets of finishing and intermediate teeth of the round broaches



<table>
<tr><th rowspan="2">Teeth diameter, mm</th><th colspan="2">z_C=2</th><th rowspan="2">Teeth diameter, mm</th><th colspan="2">z_C=2</th></tr>
<tr><th>N</th><th>a_1</th><th>N</th><th>a_1</th></tr>
<tr><td>6…7</td><td rowspan="8">4</td><td>1.8</td><td>38…40</td><td rowspan="7">10</td><td>5.5</td></tr>
<tr><td>7…8</td><td>2.0</td><td>40…42</td><td>4.5</td></tr>
<tr><td>8…9</td><td>2.2</td><td>42…45</td><td>5.0</td></tr>
<tr><td>9…10</td><td>2.5</td><td>45…48</td><td>5.5</td></tr>
<tr><td>10…11</td><td>3.0</td><td>48…50</td><td>5.5</td></tr>
<tr><td>11…12</td><td>3.5</td><td>50…52</td><td>6.0</td></tr>
<tr><td>12…13</td><td>4.0</td><td>52…55</td><td>6.5</td></tr>
<tr><td>13…14</td><td>4.0</td><td>55…60</td><td rowspan="5">12</td><td>5.5</td></tr>
<tr><td>14…15</td><td rowspan="9">6</td><td>4.5</td><td>60…63</td><td>6.0</td></tr>
<tr><td>15…16</td><td>3.0</td><td>63…65</td><td>6.5</td></tr>
<tr><td>16…17</td><td>3.5</td><td>65…70</td><td>7.0</td></tr>
<tr><td>17…18</td><td>3.5</td><td>70…75</td><td>7.5</td></tr>
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<tr><td>19…20</td><td>3.5</td><td>80…85</td><td>7.5</td></tr>
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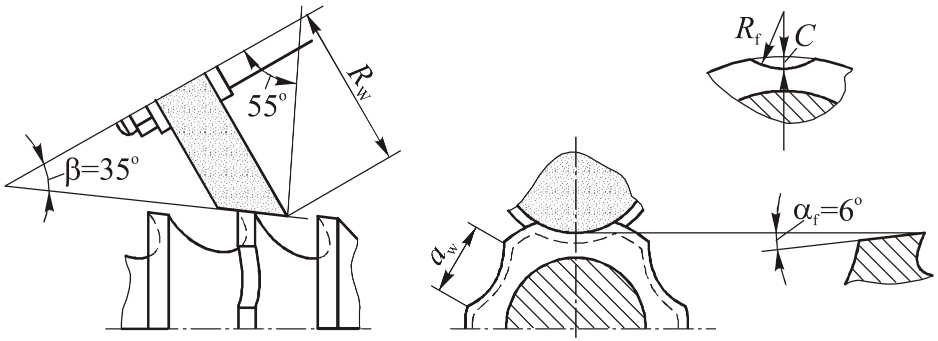
<tr><td>24…25</td><td>5.0</td><td>95…100</td><td rowspan="8">16</td><td>9.0</td></tr>
<tr><td>25…26</td><td rowspan="7">8</td><td>3.5</td><td>100…105</td><td>7.0</td></tr>
<tr><td>26…28</td><td>4.0</td><td>105…110</td><td>8.0</td></tr>
<tr><td>28…30</td><td>4.5</td><td>110…120</td><td>8.5</td></tr>
<tr><td>30…32</td><td>4.5</td><td>120…125</td><td>9.0</td></tr>
<tr><td>32…34</td><td>5.0</td><td>125…130</td><td>9.0</td></tr>
<tr><td>34…36</td><td>5.0</td><td rowspan="2">130…140</td><td rowspan="2">10.0</td></tr>
<tr><td>36…38</td><td>5.5</td></tr>
</table>

Note:

1. The fillets are arranged in a staggered fashion on the adjacent teeth.
2. The fillet of the first intermediate tooth is positioned opposite to the cutting sector of the last roughing tooth.

Table 2.28

The maximum permissible radius R_f (mm) of the fillet and radius of the grinding wheel R_w (mm) depending on the broach diameter and fillet width



Fillet width a_w, mm	Broach diameter, mm													
	To 10		10…18		18…30		30…50		50…80		80…120		120…180	
	R_w	R_f	R_w	R_f	R_w	R_f	R_w	R_f	R_w	R_f	R_w	R_f	R_w	R_f
To 3	22.5	27	22.5	27	–	–	–	–	–	–	–	–	–	–
Over 3…4	22.5	27	22.5	27	25	30	–	–	–	–	–	–	–	–
Over 4…6	22.5	27	22.5	27	25	30	25	30	–	–	–	–	–	–
Over 6…8	–	–	22.5	27	25	30	25	30	25	30	–	–	–	–
Over 8…10	–	–	–	–	25	30	25	30	25	30	30	36	–	–
Over 10…12	–	–	–	–	–	–	30	36	30	36	30	36	–	–
Over 12…15	–	–	–	–	–	–	30	36	35	42	35	42	40	48
Over 15…20	–	–	–	–	–	–	30	36	35	42	40	48	45	54

Note: 1. In some cases it is allowed to increase the radius, provided that the fillet depth C is not less than $3a_z$ of the corresponding tooth.
2. Fillets with width larger than 20 mm are cut by a wheel of 50…150 mm in diameter.
3. The grinding wheel radius R_w should be denoted on the broach drawing.
4. The fillet radius (mm) is calculated by the equation: $R_f=R_w/\cos\beta$.

Table 2.29

Transition cone length

Broach diameter, mm	To 30	Over 30 to 70	Over 70
Transition cone length, mm	15	20	25…30

Table 2.30

Rear pilot dimensions

Diameter *D*, mm	To 13	Over 13 to 23	Ov. 23 to 30	Ov.30 to 35	Ov.35 to 45	Ov.45 to 55	Ov.55 to 60	Ov.60 to 70	Ov.70 to 90	Ov.90 to 100	Over 100
Длина l_{RP}, мм	20	20	25	30	35	40	45	50	60	70	80
Chamfer *c*, mm	0.5	1.0	1.6	1.6	1.6	2	2	2	2.5	2.5	3

24. The total length of the broach is calculated by the following equation:

$$L = L_1 + L_C + l_{RP}.$$

The total length of a round broach of 10…130 mm in diameter shouldn't be larger 1750 mm ($L \leq 40D$), according to «Moskovskiy instrumentalniy zavod» LLC, since it cannot exceed broaching machine stroke, maximum distance between centers of the grinding and sharpening machines, as well as the depth of the salt-bath that is used for broach hardening. Otherwise, a set of two or three broaches is used.

25. Finally, the working drawing of the broach (refer to App. 5) is made on scale 1:1 or 2:1 on sheets of A2 or A3 size, and the calculations report is written. The broach drawing should include a broach view and cross-sections along the broach axis for different teeth rows with specified dimensional tolerances and surface finish requirements. It is desirable to draw the cross sections scaled-up compared to the broach front view. It is required to designate the welding seam position, center holes dimensions, hardness and other requirements. The drawing should include table with teeth dimensions and tolerances as well as clearance angles for roughing, intermediate, finishing and sizing teeth. The report paper should be supplemented with a list of references.

The drawings of the form cutter and the broach should be stitched together with the report paper.

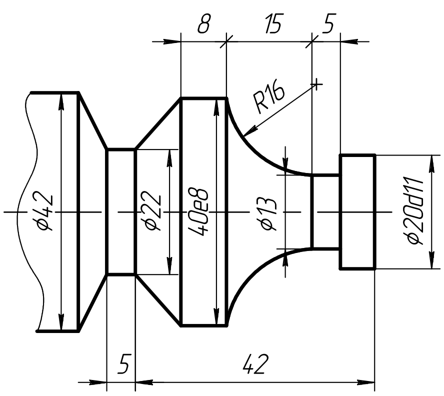
References

1) Справочник конструктора-инструментальщика / Под общ. ред. В.А. Гречишникова и С.В. Кирсанова. – М.: Машиностроение, 2006. – 542 с.
2) Протяжки для обработки отверстий / Д.К. Маргулис, М.М. Тверской, В.Н. Ашихмин и др. –М.: Машиностроение, 1986. – 232 с.
3) Кожевников Д.В., Гречишников В.А., Кирсанов С.В., Кокарев В.И., Схиртладзе А.Г. Режущий инструмент: Учебник для вузов / Под ред. С.В. Кирсанова. – М.: Машиностроение, 2007. – 528 с.

APPENDIXES

Appendix 1 Initial data for the form cutter designing

№	Part drawing	Cutter type	Workpiece material	№	Part drawing	Cutter type	Workpiece material
1	a	circular	Aluminum	26	b	prismatic	Bronze
2	b	prismatic	Copper Ml	27	c	circular	Steel 18ХГ
3	c	circular	Bronze	28	d	prismatic	Cast-iron АЧС-1
4	d	prismatic	Steel 45	29	e	circular	HSS P9
5	e	circular	Cast-iron СЧ15	30	f	prismatic	Cast-iron СЧ-40
6	f	prismatic	Steel St.3	31	a	circular	Steel 9XC
7	a	circular	Steel 20	32	b	prismatic	Aluminum AL-3
8	b	prismatic	Steel 40	33	c	circular	Steel St.3
9	c	circular	Steel 38XA	34	d	prismatic	Steel 20X
10	d	prismatic	Steel 65Г	35	e	circular	Aluminum
11	e	circular	Steel 20XH	36	f	prismatic	Bronze
12	f	prismatic	Cast-iron СЧ15	37	a	circular	Steel У7А
13	a	circular	Bronze	38	b	prismatic	Steel 38ХГН
14	b	prismatic	Brass	39	c	circular	Cast-iron СЧ24
15	c	circular	Aluminum	40	d	prismatic	Bronze
16	d	prismatic	Copper M3	41	e	circular	Brass
17	e	circular	Steel ШХ15	42	f	prismatic	Steel 15ХФ
18	f	prismatic	Steel 15ХФ	43	a	circular	Steel 45
19	a	circular	Steel 80	44	b	prismatic	Steel 45Г2
20	b	prismatic	Cast-iron КЧ40-3	45	c	circular	Cast-iron КЧ35-1О
21	c	circular	Steel 30	46	d	prismatic	Steel 38ХГН
22	d	prismatic	Cast-iron СЧ21	47	e	circular	Steel У12А
23	e	circular	Bronze	48	f	prismatic	Cast-iron АЧС-1
24	f	prismatic	Copper M3	49	a	circular	Brass
25	a	circular	Cast-iron СЧ20	50	b	prismatic	Steel 50



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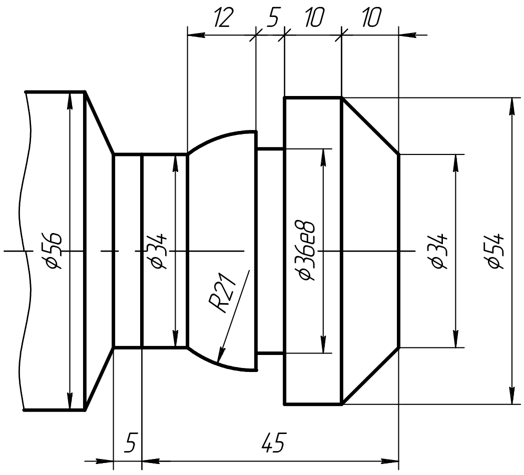

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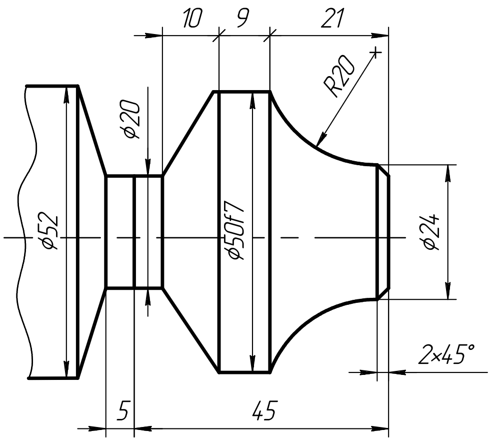

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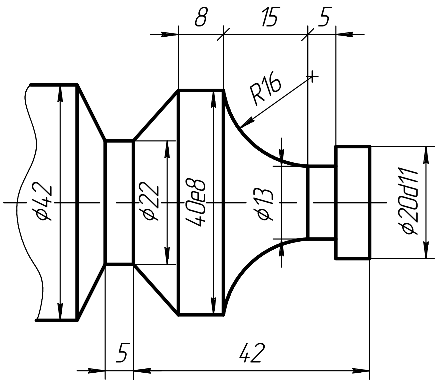

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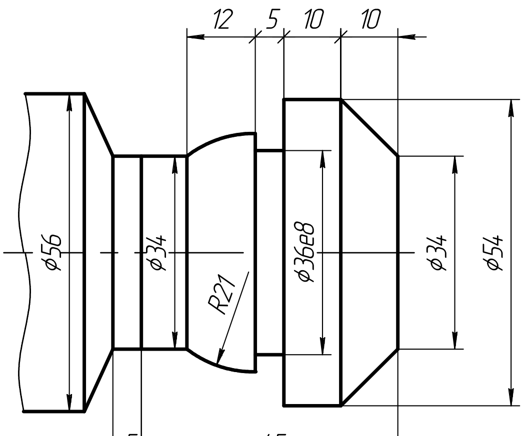

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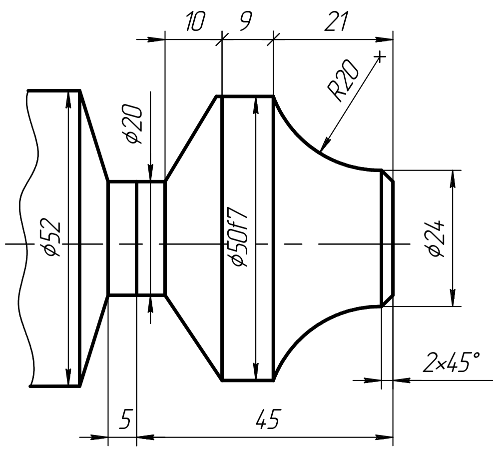

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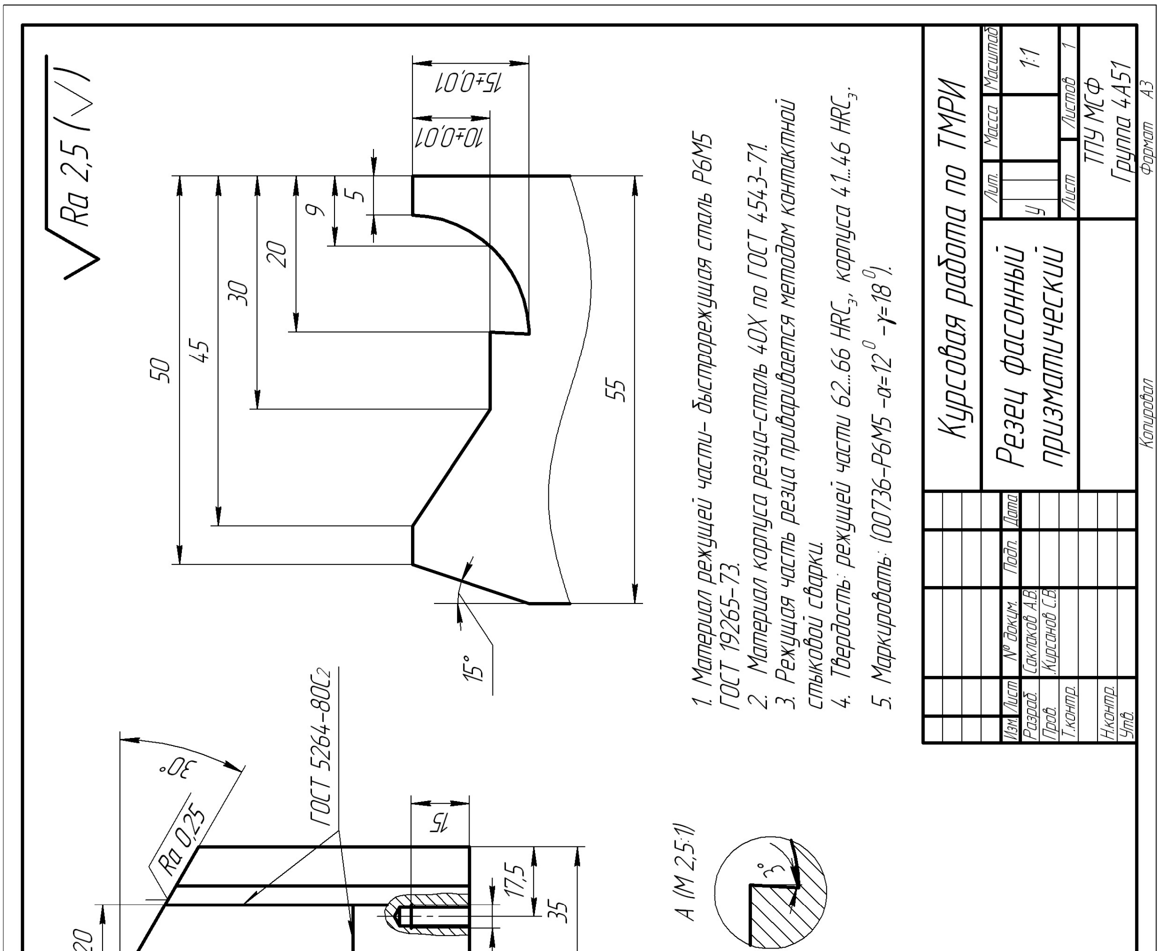
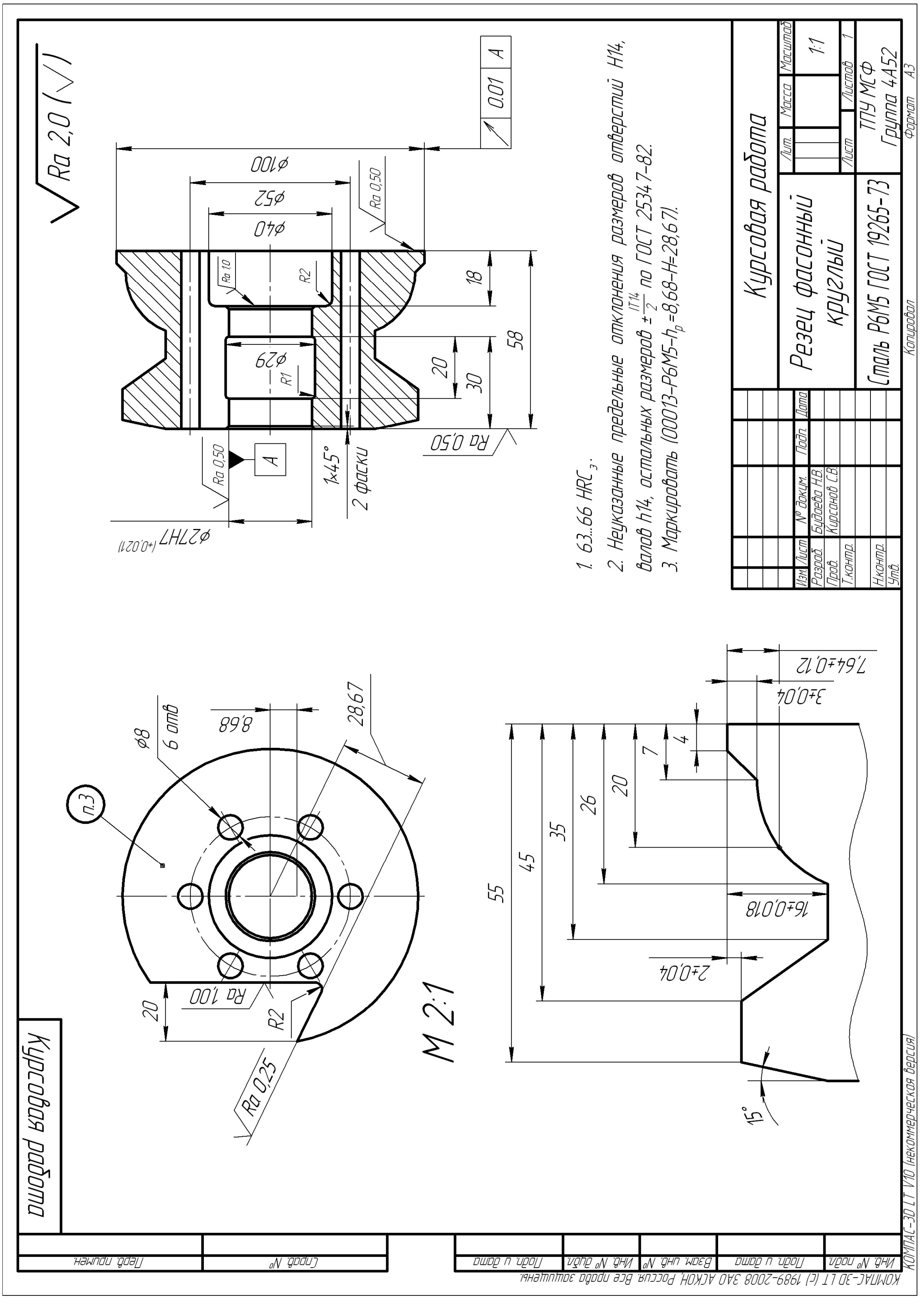
Part drawings for Table of Appendix 1

Appendix 2 Example of a drawing for a prismatic form cutter



Appendix 3 Example of a drawing for a circular form cutter



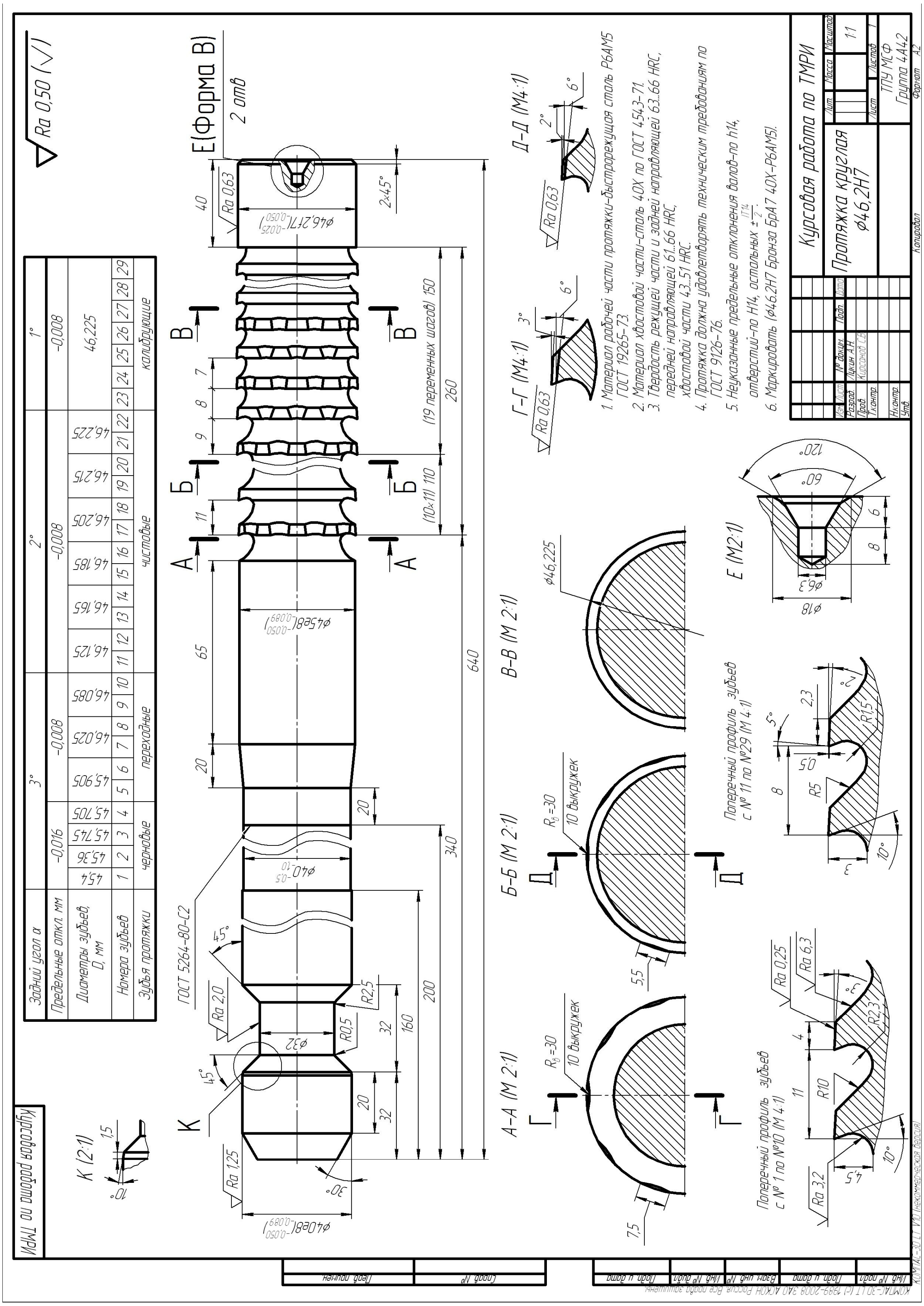
Appendix 4 Initial data for the rotor-cut round broach designing

№	Initial bore before broaching *d*, mm H12	Part hole length, mm	After broaching			Workpiece material	Hardness *HB*	Broaching machine parameters		
			D, mm	Accuracy grade	*Ra*, μm			Model	Pulling force, kN	Stroke, mm
1	2	3	4	5	6	7	8	9	10	11
1.	45	90	46	*H*7	2.5	Steel 40Х	240	7А523	100	1250
2.	21	30	22	*H*8	1.25	Cast-iron СЧ12	175	7А523	100	1250
3.	24.2	60	25	*H*9	2.5	Steel 45	210	7В56	196	1600
4.	48	80	50	*H*8	1.25	Steel 30	179	7В55	98	1250
5.	27	62	28.2	*H*7	2.5	Steel 15ХФ	230	7В57	32	2000
6.	28	62	30	*H*8	1.25	Steel 40ХС	220	7В54	49	1000
7.	29	64	31.5	*H*9	*Rz* 20	Steel 50	240	7В58	74	2000
8.	30	66	31.8	*H*8	2.5	Cast-iron СЧ18	180	7А520	195	1600
9.	31	70	32.5	*H*9	*Rz* 20	Cast-iron КЧ35-10	163	7Б75	98	1250
10.	33	72	34.6	*H*9	2.5	Bronze Бр.А7	90	7Б66	196	1250
11.	37	75	38.8	*H*10	*Rz* 40	Steel ШХ15	220	7Б67	392	1600
12.	39	78	41	*H*9	1.25	Steel 55Г	269	7Б64	49	1000
13.	42	80	44	*H*7	2.5	Steel 30Х	187	7Б68	784	1600
14.	43	90	45	*H*9	*Rz*20	Steel 45Х	217	7Б55У	98	1250
15.	44	92	45.6	*H*8	2.5	Steel 40ХГТ	241	7Б66	196	1600
16.	46	95	47.8	*H*9	1.25	Cast-iron СЧ15	197	7Б55	98	1250
17.	48	98	49.6	*H*7	1.25	Steel 20Х	179	7Б57	32	2000
18.	51	100	52.3	*H*8	2.5	Steel 40Х	207	7Б54	49	1000
19.	54	110	56	*H*7	1.25	Steel 45ХН	241	7Б58	74	2000
20.	56	112	58	*H*9	*Rz* 20	Steel 40	217	7А520	196	1600
21.	34	50	35.5	*H*8	2.5	Steel 40ХГТ	241	7Б75	98	1250
22.	36	80	37.4	*H*8	2.5	Steel 50	220	7Б66	196	1250
23.	38	70	39.2	*H*9	2.5	Cast-iron СЧ15	179	7Б67	392	1600
24.	40	55	41.3	*H*8	2.5	Steel 45	196	7Б64	49	1000
25.	45	90	46.2	*H*7	1.25	Bronze Бр.А7	100	7Б68	784	1600
26.	50	110	51.3	*H*9	*Rz*20	Cast-iron СЧ18	160	7Б55У	98	1250

End of the Table of Appendix 4

1	2	3	4	5	6	7	8	9	10	11
27.	52.8	105	54	*H*7	1.25	Steel 40X	220	7Б56	196	1600
28.	55	100	56.2	*H*9	*Rz* 20	Cast-iron КЧ30-6	160	7Б55	98	1250
29.	50	110	51.3	*H*8	2.5	Steel 40XC	230	7Б57	32	2000
30.	60	100	61.5	*H*7	1.25	Steel 60Г	250	7Б54	49	1000
31.	61	110	63	*H*8	2.5	Steel 35	220	7Б58	74	2000
32.	62	120	63.6	*H*8	2.5	Steel 40	235	7A520	196	1600
33.	63	108	64.4	*H*7	1.25	Steel 45Г2	270	7Б75	98	1250
34.	64	130	66	*H*9	2.5	Aluminum AK4-1	170	7Б56	196	1250
35.	65	125	66.2	*H*8	2.5	Brass ЛК80-3	147	7B67	392	1600
36.	66	132	67.6	*H*9	*Rz*20	Cast-iron СЧ12	185	7Б64	49	1000
37.	67	140	69	*H*8	2.5	Steel 45	198	7Б68	784	1600
38.	68	142	69.8	*H*9	1.25	Steel 50	210	7Б55У	98	1250
39.	69	140	71	*H*8	2.5	Steel 20X	214	7Б56	196	1600
40.	70	138	71.8	*H*8	2.5	Steel 35Г2	230	7Б55	98	1250
41.	71	140	72.6	*H*7	1.25	Steel 60Г	241	7B57	32	2000
42.	72	142	73.9	*H*9	2.5	Steel 20	195	7B54	49	1000
43.	73	146	74.7	*H*9	*Rz*20	Cast-iron СЧ40	214	7B58	74	2000
44.	74	140	75.8	*H*8	2.5	Steel 50	228	7A520	196	1600
45.	75	148	77	*H*8	1.25	Brass ЛК80-3	131	7Б75	98	1250
46.	76	150	78.2	*H*7	1.25	Steel 45	220	7Б66	196	1250
47.	77	152	78.4	*H*8	2.5	Steel A30	186	7Б67	392	1600
48.	78	158	79.6	*H*9	2.5	Steel 20X	218	7Б64	49	1000
49.	79	156	80.8	*H*9	2.5	Steel 45	200	7Б68	784	1600
50.	80	160	82.2	*H*10	*Rz*20	Cast-iron СЧ15	182	7Б56	195	1600

Appendix 5 Example of a drawing for a rotor-cut round broach



Educational Edition

КИРСАНОВ Сергей Васильевич

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Методические указания

к выполнению курсовой работы по дисциплине «Резание материалов и режущий инструмент»

На английском языке

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