# 12 Broaching

## 12.1 Definition

Broaching is a metal cutting technique with a multi-edged tool in which the tool performs the cutting motion. This method functions without any feed motion due to the offset of the cutting teeth on the broaching tool.

The material is removed in one stroke (pulling or pushing) with the broaching tool, called the broach.

## 12.2 Broaching methods

In broaching, two working procedures – internal- and external broaching - are distinguished.

### 12.2.1 Internal broaching

During internal broaching, the broaching tool is brought into the premachined opening of the workpiece. Working motion then begins, whereby the broach, equipped with many cutting blades, is pulled or pushed through. The broach contour (square, hexagon, etc.) is generated in the workpiece opening.

Figure 12.1 elucidates the configuration of workpiece and tool during broaching.

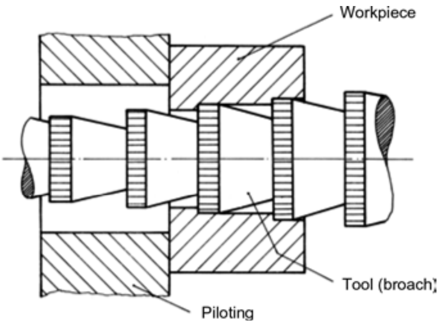

**Figure 12.1**
Broaching principle

### 12.2.2 External broaching

During external broaching, the broaching tool finishes a premachined outer workpiece contour, such as the opening of a forged open-end wrench.

## 12.3 Application of the broaching techniques

### 12.3.1 Internal broaching

Internal broaching is applied to generate openings of different shapes. Thus, for example, serrations, taper bushings for splines, and spline profiles for movable gears are created with this method. Some typical examples are seen in Figure 12.2.

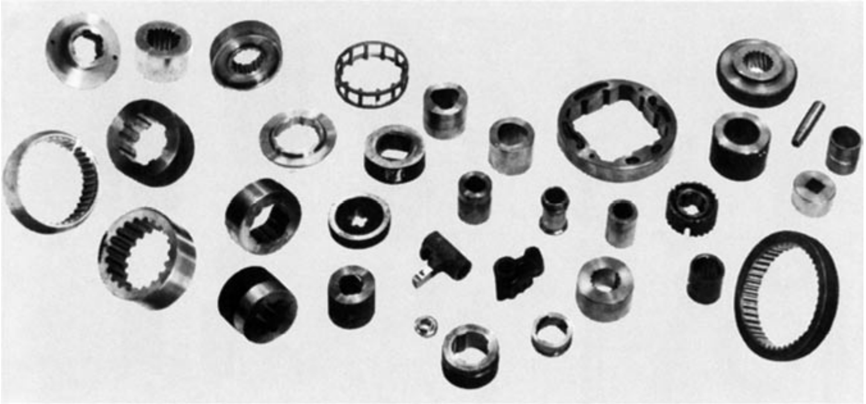

**Figure 12.2**
Broaching profiles for internal broaching
(*photo by Karl Klink, Niefern*)

As a rule, broaching is used if high accuracy to shape and size is demanded in addition to high surface quality. For this reason, broaching is sometimes used instead of reaming to generate holes.

Broaching is an economical procedure since it is possible to produce very sophisticated geometries that require no further reworking very quickly and with a single stroke.

The generation of a spline profile in internal broaching is illustrated in Figure 12.3.

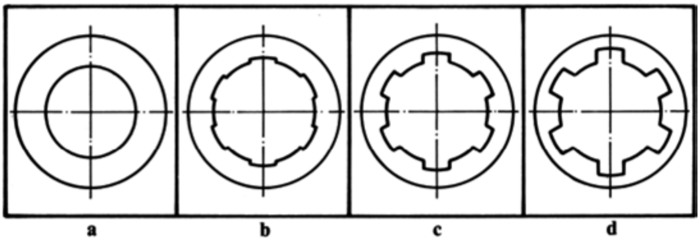

**Figure 12.3**
Generation of an internal spline during internal broaching
a - before; b and c – during; d – at the end of the broaching procedure

### 12.3.2 External broaching

External broaching is the method used for the generation of external profiles. However, this method is also used for the manufacturing of shaped grooves, such as Christmas tree-shaped grooves (Figure 12.4c), in which the turbine blades are mounted in turbine wheels.

External broaching is also applied for machining of external teeth (Figure 12.4b) and guiding surfaces (Figure 12.4d), as well as guide grooves and similar items.

Figure 12.4 shows some typical workpieces for external broaching.

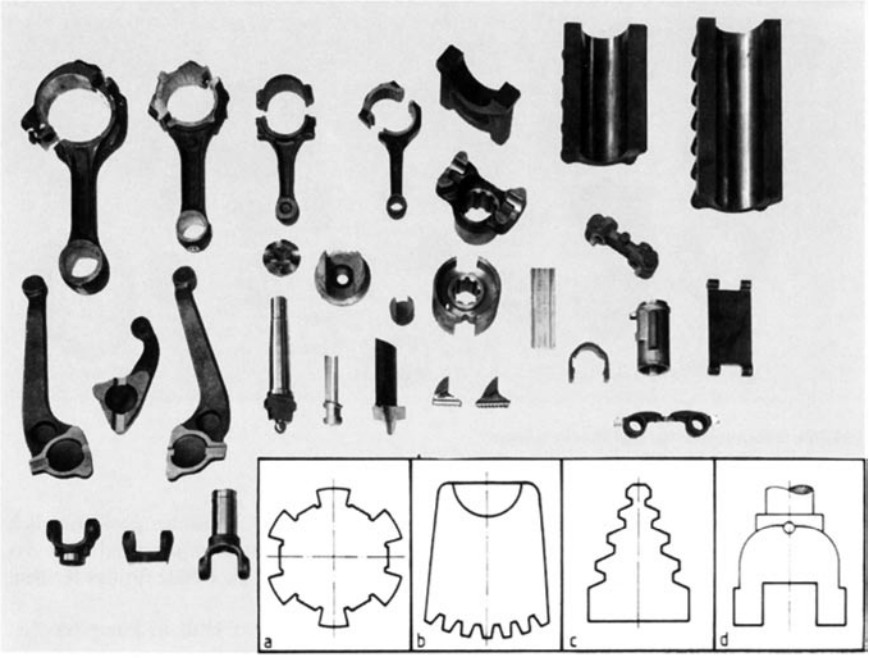

**Figure 12.4**
Broaching profiles to be produced by external broaching
(*photo by Karl Klink, Niefern*)

## 12.4 Achievable accuracy values

### 12.4.1 Accuracy to size

The accuracy values that can definitely be achieved with internal- and external broaching range from

IT 7 to IT 8.

However, with more effort, it is also possible to achieve

IT 6.

For internal broaching, permissible tolerances for hubs and hub-like profiles can be taken from the following DIN sheets:

| *DIN* | *Profile type* |
|---|---|
| 5465 | Splines with straight-lined flanks |
| 5471/72 | Internal splines with 4 or 6 splines |
| 5480 | Involute splines |
| 5481 | Serrations |
| 5482 | Internal- and external splines with involute toothing |

### 12.4.2 Surface quality

The final finishing tooth that cuts in the offset at a depth of $h = 0{,}01$ mm has a substantial effect on surface quality.

Furthermore, reserve teeth are included in internal broaching. These teeth improve the surface by regrooving and shaving.

During the generation of profiled surfaces with all the teeth of a broaching tool or of straight surfaces by broaching tools with lateral offset, the surface is influenced by the minor cutting edges of these tools. The surface roughness values $R_\mathrm{t}$ that can be achieved during broaching of mild steels range from

$$R_\mathrm{t} = 6{,}3 \text{ to } 25\ \mu\mathrm{m}$$

High surface qualities can also be achieved in the case of easily broached free cutting steels and materials for casting.

Acceptable broaching results may also be expected from case hardening- and tempering steels, if a homogeneous ferrite-, perlite distribution is available for normally annealed material.

## 12.5 Calculation of force and power

During broaching, the cutting edge angle $\varkappa$ is

$\boxed{\varkappa = 90^\circ}$ for internal broaching and

$\boxed{\varkappa = 90 - \lambda}$ for external broaching

$\lambda$ in ° tool cutting edge inclination (Figure 12.9).

From this, we may conclude:

### 12.5.1 Width of cut *b* (Figure 12.5)

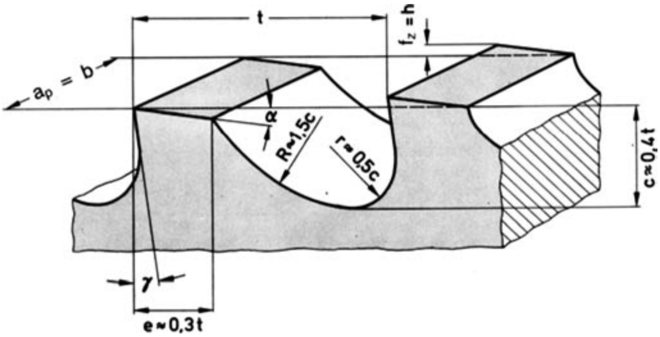

**Figure 12.5**
Cutting variables during broaching
*t* pitch, *e* tooth back thickness, *c* tooth space depth, *r* rake face radius, $f_z$ stepping of the cutting edges (feed per cutting edge), $a_p$ broach width

$$\boxed{b = a_p}$$ for internal broaching

$$\boxed{b = \frac{a_p}{\cos\lambda}}$$ for external broaching (see Figure 12.9)

| | | |
|---|---|---|
| $a_p$ | in mm | broach width |
| $b$ | in mm | width of cut |
| $\lambda$ | in ° | tool cutting edge inclination (Figure 12.9) |

### 12.5.2 Thickness of cut *h*

$$\boxed{h = f_z}$$

| | | |
|---|---|---|
| $h$ | in mm | thickness of cut |
| $f_z$ | in mm | feed per cutting edge |

### 12.5.3 Specific cutting force

$$\boxed{k_c = \frac{(1\,\text{mm})^z}{f_z^z} \cdot k_{c1,1} \cdot K_\gamma \cdot K_{ver} \cdot K_v \cdot K_{st}}$$

| | | |
|---|---|---|
| $K_c$ | in N/mm$^2$ | specific cutting force |
| $k_{c1,1}$ | in N/mm$^2$ | specific cutting force related to $h = b = 1$ mm |
| $K_\gamma$ | | correction factor for the rake angle $\gamma$ |
| $K_{ver}$ | | correction factor for tool wear<br>$K_{ver} = 1,3$ |
| $K_{st}$ | | correction factor for chip compression<br>$K_{st} = 1,1$ |
| $K_v$ | | correction factor for the cutting speed<br>$K_v = 1$ for cemented carbide cutting edges<br>$K_v = 1,15$ for cutting edges made of high speed steel |

$$\boxed{K_\gamma = 1 - \frac{\gamma_{\text{tat}} - \gamma_0}{100}}$$

$\gamma_{\text{tat}}$ = real rake angle
$\gamma_0$ = 6° for steel
$\gamma_0$ = 2° for grey cast iron

## 12.5.4 Major cutting force per cutting edge

$$\boxed{F_{\text{cz}} = a_{\text{p}} \cdot f_{\text{z}} \cdot k_{\text{c}}}$$

| | | |
|---|---|---|
| $F_{\text{cz}}$ | in N | major cutting force per cutting edge |
| $a_{\text{p}}$ | in mm | broach width |
| $f_{\text{z}}$ | in mm | feed per cutting edge |
| $A$ | in mm$^2$ | sectional area of chip ($A = a \cdot f_z$) |

## 12.5.5 Number of teeth in contact

$$\boxed{z_{\text{E}} = \frac{l}{t}}$$

| | | |
|---|---|---|
| $z_{\text{E}}$ | | number of teeth in contact |
| $l$ | in mm | broaching length in the workpiece (see Figure 212) |
| $t$ | in mm | toothing pitch |

## 12.5.6 Toothing pitch

Pitch *t* of the broach is understood as the distance from cutting edge to cutting edge (Fig. 12.5).

Pitch should be selected in a way that at least 2 teeth are in contact. However, care should also be taken to ensure that too many teeth are not in contact; otherwise, the required broaching force would exceed the transforming capacities of the broaching cross section or the stroke-related force of the broaching machine.

To avoid vibrations that result in chatter marks in broaching, pitch is varied from tooth to tooth by 0,1 to 0,3 mm.

Broach length *l* corresponds to the length to be broached in the workpiece. For a workpiece with throughhole, *l* corresponds to the length of the workpiece. If the workpiece has a recess (Figure 12.6b), then *l* is composed of the partial lines $l_1$ and $l_2$.

$$\boxed{l = l_1 + l_2}$$

Minimal permissible pitch can be determined from the following criteria.

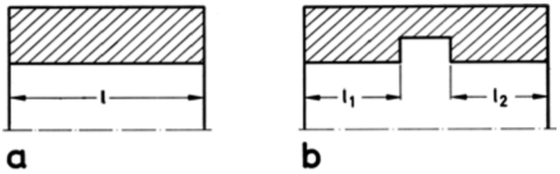

**Figure 12.6**
Workpiece length for broaching
a) workpiece with throughhole,
b) workpiece with offset hole

### 12.5.6.1 Minimal permissible tooth pitch according to the force available in the broaching machine

$$F_c \le F_M \qquad F_c = F_{cz} \cdot z_E$$

From $a_p \cdot f_z \cdot k_c \cdot Z_E \le F_M$ we obtain: $$z_{E_{max}} = \frac{F_M}{a_p \cdot f_z \cdot k_c}$$

$$\boxed{t_{min} = \frac{l}{z_{E_{max}}} = \frac{l \cdot a_p \cdot f_z \cdot k_c}{F_M}}$$

| | | |
|---|---|---|
| $t_{min}$ | in mm | minimal permissible tooth pitch |
| $L$ | in mm | broaching length in the workpiece |
| $z_{E\,max}$ | | maximal number of teeth in contact |
| $F_M$ | in N | broaching force (stroke) of the broaching machine |
| $a_p$ | in mm | broach width |
| $f_z$ | in mm | feed per cutting edge |
| $F_c$ | in N | major cutting force |

### 12.5.6.2 Minimal permissible tooth pitch according to the required chip space

$$\boxed{t_{min} \approx 3 \cdot \sqrt{l \cdot f_z \cdot C}}$$

| | | |
|---|---|---|
| $t_{min}$ | in mm | minimal permissible tooth pitch |
| $l$ | in mm | broaching length in the workpiece |
| $C$ | | chip space number |

In this empiric equation, the required chip space is considered via chip space number $C$.

**Table 12.1** Chip space number $C$

| Material | Chip space number $C$ | | | |
|---|---|---|---|---|
| | Internal broach | | External broach | |
| | Flat | Round | with | |
| | | | Offset in depth | Lateral offset |
| Steel | 5–8 | 8–16 | 4–10 | 1,8–6 |
| Cast steel | 6 | 12 | 7 | 4 |
| Grey cast iron | 6 | 12 | 7 | 4 |
| Non-ferrous metals | 3–7 | 6–14 | 3–7 | 1–5 |

(excerpt from reference tables by Hoffmann, Pforzheim)

### 12.5.6.3 Minimal permissible tooth pitch according to the permissible force the broach cross-section is able to transform

$$F_c \le F$$

$$F_c \le A_0 \cdot \sigma_{zul}$$

In this case, the major cutting force $F_s$ required for broaching must not exceed the permissible force $F$ that the core cross-section of the broach is able to transform.

From this, we derive:

$$\boxed{t_{\min} = \frac{l \cdot a_p \cdot f_z \cdot k_c}{A_0 \cdot \sigma_{zul}}}$$

| | | |
|---|---|---|
| $t_{\min}$ | in mm | minimal permissible tooth pitch |
| $l$ | in mm | broaching length in the workpiece |
| $A_0$ | in mm$^2$ | core cross-section of the broach |
| $\sigma_{zul}$ | in N/mm$^2$ | permissible broaching stroke stress of the broach material |

Since the broach is dimensioned by the manufacturer, the user of the broach need not do this confirmative calculation.

### 12.5.7 Major cutting force

$$\boxed{F_c = a_p \cdot f_z \cdot k_c \cdot z_E}$$

| | | |
|---|---|---|
| $F_c$ | in N | major cutting force |
| $a_p$ | in mm | broach width |
| $f$ | in mm | feed per cutting edge |
| $k_c$ | in N/mm$^2$ | specific cutting force |
| $z_E$ | | number of cutting edges in contact |

### 12.5.8 Machine input power

$$\boxed{P = \frac{F_c \cdot v_c}{60\ \text{s/min} \cdot 10^3\ \text{W/kW} \cdot \eta_M}}$$

| | | |
|---|---|---|
| $P$ | in kW | machine input power |
| $F_c$ | in N | major cutting force |
| $v_c$ | in m/min | cutting speed |
| $\eta_M$ | | machine efficiency |

## 12.6 Calculation of the machining time

For broaching, the machining time is composed of the individual times for cutting motion and return stroke.

$$t_h = \frac{H}{v_c} + \frac{H}{v_r}$$

$$\boxed{t_h = \frac{H(v_c + v_r)}{v_c \cdot v_r}}$$

| | | |
|---|---|---|
| $t_h$ | in min | machining time for one work cycle (cutting- and return stroke) |
| $H$ | in m | required stroke |
| $v_c$ | in m/min | cutting speed |
| $v_r$ | in m/min | return speed |

### 12.6.1 Work cycle during internal broaching (Figure 12.7)

For internal broaching, work cycle *H* (Figure 12.7) is composed of the following parameters:

$$\boxed{H = 1{,}2 \cdot l + a_2 + a_3 + l_2}$$

| | | |
|---|---|---|
| $H$ | in mm | stroke during internal broaching |
| $l$ | in mm | broaching length in the workpiece (see Figure 12.6, Chapter 12.5.6) |
| $a_2$ | in mm | length of the cutting portion |
| $a_3$ | in mm | pilot length |
| $l_2$ | in mm | rear support length |

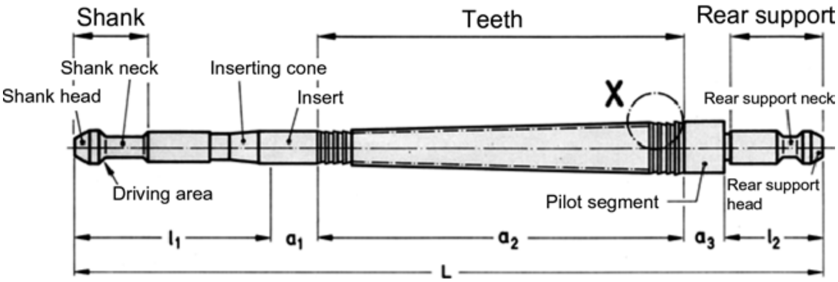

**Figure 12.7**
Broach components
$l_1$ shank, $a_1$ pilot, $a_2$ cutting portion, $a_3$ pilot, $l_2$ rear support, *L* total length detail X see Figure 12.9

### 12.6.2 Working stroke during external broaching (Figure 12.8)

$$\boxed{H = 1{,}2 \cdot L + l_a + w}$$

| | | |
|---|---|---|
| $H$ | in mm | stroke during external broaching |
| $L$ | in mm | tool length |
| $l_a$ | in mm | thickness of the closing plate |
| $w$ | in mm | workpiece height |

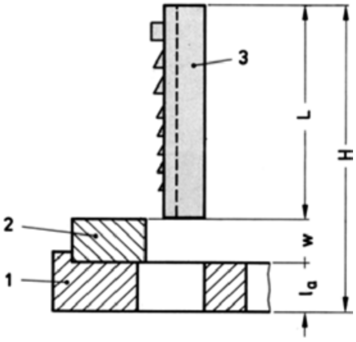

**Figure 12.8**
External broaching – working principle
1 closing plate, 2 workpiece, 3 broaching tool

### 12.6.3 Length of the cutting portion (Figure 12.7)

$$\boxed{a_2 = t_1 \cdot z_1 + t_2 \cdot (z_2 + z_3)}$$

| | | |
|---|---|---|
| $a_2$ | in mm | length of the cutting portion |
| $t_1$ | in mm | pitch of the roughing teeth |
| $t_2$ | in mm | pitch of finishing- and calibrating teeth |
| $z_1$ | | number of roughing teeth |
| $z_2$ | | number of finishing teeth |
| $z_3$ | | number of calibrating teeth |

(see also Chapter 12.7.2 Broach teeth design)

## 12.7 Broaching tools

### 12.7.1 Broach – blade geometry

On broaches, rake angle and tool orthogonal clearance (Figure 12.9) have the same effect as on the turning tool (see Chapter 2.4).

Rake face chamfers reinforce the wedge and only slightly diminish the positive properties of greater rake angles. Due to complicated grinding, broaches are generally made without any rake face chamfers.

Flank wear lands with a land angle of the flank from 0° to 0,5º and a land width of 0,5 mm have only finishing- and calibrating teeth. Only small land angles of the flank with small land width are selected in order to maintain accuracy to size of the broach even in the case of repeated re-sharpening.

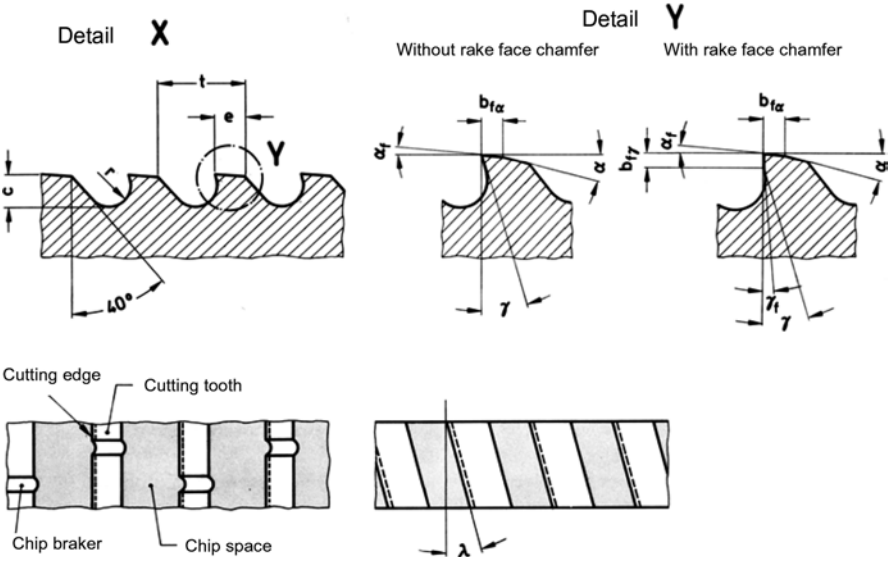

**Figure 12.9**
Cutting edge geometry of a broach according to Figure 12.7, at the bottom right, cutting edges of a broach with inclined blades

Table 12.2 below shows the order of magnitude of the angles on broaching tools.

**Table 12.2** Rake angle and tool orthogonal clearance on broaches

| Material | $\alpha$ in ° | $\gamma$ in ° |
|---|---|---|
| E 295–E 335<br>C 22–C 35 | 3 | 18–25 |
| E 360<br>C 60 | 4 | 15–20 |
| Quenched and subsequently tempered steel 1000 N/mm$^2$ | 4 | 12–18 |
| Tool steel | 4 | 12–18 |
| Grey cast iron | 3 | 8–15 |
| Al alloy.<br>9–13% Si | 4 | 18–25 |
| Brass, bronze | 4 | 5–20 |

In internal broaches, tool cutting edge inclination $\lambda$ is defined as $\lambda = 0°$ to avoid high cost for regrinding.

For external broaches, chosen tool cutting edge inclination ranges from 3° to 20°. Inclination of cutting edges brings the following advantages:

1. gradual approach contact of the blade,
2. lower cutting forces – no pulse-like load that could result in vibrations,
3. easier chip removal sidewise.

For external broaching, the following values are recommended for the tool cutting edge inclination:

| | |
|---|---|
| Surface broaching in offset in depth | $\lambda < 20°$ |
| Profile broaching in offset in depth | $\lambda < 3°$ |
| Lateral offset | $\lambda < 15°$ |

## 12.7.2 Broach teeth design

The tooth space (Figure 12.9) is formed by the 3 parameters

tooth space depth $c$
rake face radius $r$
pitch $t$.

The tooth space has to be shaped so that the chips necessarily roll up (Figure 12.10). Chip clogging in the tooth space results in breaking off of teeth and generates jams and inexact contours on the workpiece's outgoing side.

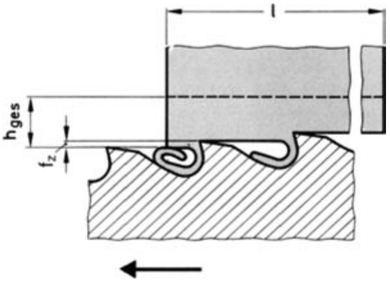

**Figure 12.10**
Formation of the tooth space

### 12.7.2.1 Minimal permissible pitch *t*

is calculated according to the equation under 12.5.6.2 and given in mm.

$$\boxed{t_{\min} = 3 \cdot \sqrt{l \cdot f_z \cdot C}}$$

| | | |
|---|---|---|
| $C$ | | chip space number |
| $l$ | in mm | broaching length in the workpiece |

### 12.7.2.2 Tooth space depth *c*

(Figure 12.9) is taken from:

$$\boxed{C \approx 0{,}35 \cdot t}$$

| | | |
|---|---|---|
| $c$ | in mm | tooth space depth |
| $t$ | in mm | pitch |

### 12.7.2.3 Tooth back thickness *e*

and rake face radius are to be selected in the ranges given below

$e = 1{,}1 - 8$ mm
$r = 0{,}8 - 5$ mm

Both values can be calculated in good approximation

$$\boxed{\begin{array}{l} e \approx 0{,}3 \cdot t \\ \hline r \approx 0{,}6 \cdot c \end{array}}$$

The cutting tooth parameters are defined in DIN 1416.

**Table 12.3** Cutting tooth sizes (excerpt from DIN 1416)

| Pitch *t* in mm | Tooth space depth *c* in mm | Tooth back thickness *e* in mm | Rake face radius *r* in mm |
|---|---|---|---|
| 3,5 | 1,2 | 1,1 | 0,8 |
| 4 | 1.4 | 1,2 | 0,8 |
| 4,5 | 1,6 | 1,4 | 1.0 |
| 5 | 1,8 | 1,6 | 1,0 |
| 6 | 2,2 | 2,0 | 1,6 |
| 7 | 2,5 | 2,2 | 1,6 |
| ⋮ | ⋮ | ⋮ | ⋮ |
| 25 | 9 | 8 | 5 |

### 12.7.2.4 Tooth offset

Offset is understood as the chip removal predefined by the allocation of teeth (Figure 12.11). The tooth offset corresponds to the thickness of cut *h*. Since the plan angle during broaching is 90°, there is

$$\boxed{h = f_z}$$

$f_z$ in mm feed per cutting edge
$h$ in mm thickness of cut

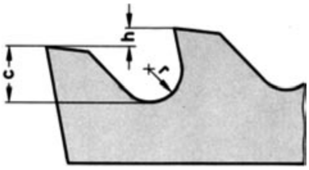

**Figure 12.11**
Tooth offset

We distinguish between offset in depth and lateral offset.

*Offset in depth* means that the feed direction is orthogonal to the broaching surface.

*Lateral offset* is available if the broaching surface is machined from the side.

Permissible thickness of cut is shown in Table 12.4.

**Table 12.4** Depth- and lateral offsets during external broaching

| Material | Thickness of cut $h$ per tooth in mm | | |
|---|---|---|---|
| | Offset in depth | | Lateral offset |
| | Roughing | Finishing | |
| S 275 JR–E 360<br>C 22–C 60 | 0,06–0,15 | 0,01–0,025 | 0,08–0,25 |
| Quenched and tempered steel 1000 N/mm$^2$ tool steel | 0,04–0,10 | 0,01–0,025 | 0,08–0,25 |
| Grey cast iron | 0,08–0,2 | 0,02–0,04 | 0,29–0,6 |
| Al alloy<br>9–13% Si | 0,1–0,2 | 0,02 | not applied |
| Brass, bronze | 0,1–0,3 | 0,02 | not applied |

**Table 12.5** Depth- and lateral offset during internal broaching

| Material | Thickness of cut $h$ per tooth in mm | | | | |
|---|---|---|---|---|---|
| | Plane-broaching tool | | Round-broaching tool | | Profile broaching tool |
| | Roughing | Finishing | Roughing | Finishing | |
| Steel<br>Cast steel | 0,04–0,1 | 0,01–0,025 | 0,01–0,03 | 0,0025–0,005 | 0,02–0,08 |
| GG<br>Non-ferrous metals | 0,05–0,15 | 0,02–0,04 | 0,02–0,04 | 0,01–0,02 | 0,04–0,1 |

(excerpt from reference tables by Kurt Hoffmann, Pforzheim)

### 12.7.2.5 **Number of cutting edges** (Figure 12.10)

a) *Total tooth number*

$$\boxed{z_w = \frac{h_{ges}}{f_z}}$$

| | | |
|---|---|---|
| $z_w$ | | total tooth number of the broach |
| $h_{ges}$ | in mm | machining allowance (Figure 12.10) |
| $f_z$ | in mm | feed per cutting edge = thickness of cut $h$ |

b) *Tooth number $z_2$ for finishing*

For finishing, 5 teeth are used on average.

$$\boxed{z_2 = 5 \text{ teeth}}$$

$z_2$ number of teeth for finishing

c) *Number of teeth $z_1$ for roughing*

$$\boxed{z_1 = \frac{h_{\text{ges}} - 5 \cdot f_{z2}}{f_{z1}}}$$

| | | |
|---|---|---|
| $z_1$ | | tooth number for roughing |
| $h_{\text{ges}}$ | in mm | machining allowance |
| $f_{z1}$ | in mm | feed per cutting edge for roughing |
| $f_{z2}$ | in mm | feed per cutting edge for finishing |

d) For calibration, one can also assume 5 teeth. However, since the calibration teeth only smooth instead of removing any allowance, this tooth number is not integrated into the calculation of $z_1$.

### 12.7.2.6 Total length of the internal broach (Figure 12.7)

$$\boxed{L = l_1 + a_1 + a_2 + a_3 + l_2}$$

| | | |
|---|---|---|
| $L$ | in mm | total length of the internal broach |
| $l_1$ | in mm | shank length |
| $a_1$ | in mm | pilot length |
| $a_2$ | in mm | length of the cutting portion |
| $a_3$ | in mm | length of the rear pilot |
| $l_2$ | in mm | length of the rear support |

The length of the external broach arises from the length of the cutting portion or the length of the cutting portion's mounting.

The design types of shanks, rear supports (Figure 12.7) and pilots are defined in DIN 1415 sheet 1.

Table 12.6 shows an excerpt from DIN 1415 for round shanks and rear supports.

**Table 12.6** Length of round shanks $l_1$ and rear supports $l_2$ in mm as a function of the broach diameter *d* in mm (Figure 12.7)

| *d* in mm | Shank length $l_2$ in mm | Rear support length $l_2$ in mm |
|---|---|---|
| 20–25 | 180 | 190 |
| 28–40 | 200 | 125 |
| ⋮ | ⋮ | ⋮ |
| 100 | 360 | 200 |

excerpt from DIN 1415 sheet 1 and sheet 4

### 12.7.2.7 Broaches - design types

A variety of broach forms is given in Figure 12.12.

For difficult profile types, the external broach is composed of several cutting portions.

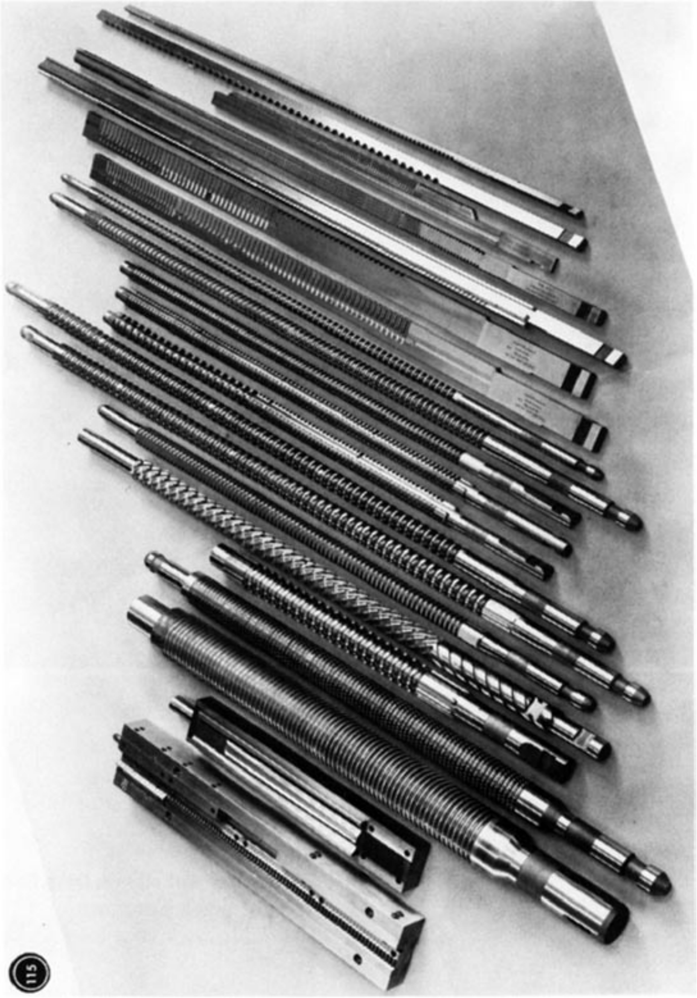

**Figure 12.12**
Broach types for internal- and external broaching
(*photo by Karl Klink, Niefern*)

Figure 12.13 elucidates a broaching tool for lateral machining composed of circular cutting portions.

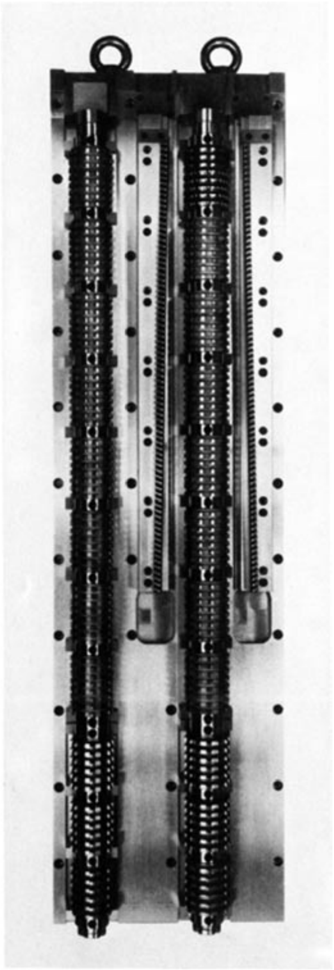

**Figure 12.13**
Tools with inserted cutting portions with straight-lined and circular contours (*photo by Karl Klink, Niefern*)

### 12.7.3 Materials for broaching tools

Broaching tools are primarily made of high speed steel. Preferentially used materials are shown below:

| *Material No.* | *DIN name* | *according to EN 96* |
|---|---|---|
| 1.3348 | S 2 - 9 – 2 | HS 2 – 9 - 2 |
| 1.3343 | SC 6 - 5 – 2 | HS 6 - 5 – 2 |
| 1.3243 | S 6 - 5 - 2 – 5 | HS 6 - 5 - 2 – 5 |

Cemented carbide is used in addition to high speed steels. In the cemented carbide tools, the backing material is made of tool steel. The cemented carbide cutting edges are inserted into the backing material.

To attach cemented carbide blades, as with the turning and milling tools, there are several possibilities. The blades may either be hard soldered or mounted on the backing material by clamping connections.

Figure 12.14 shows the principle of a clamping connection via clamping wedge.

Figure 12.15 elucidates a broach with inserted cemented carbide blades.

In these cutting portions (Figure 12.16), the cemented carbide tips are hard soldered.

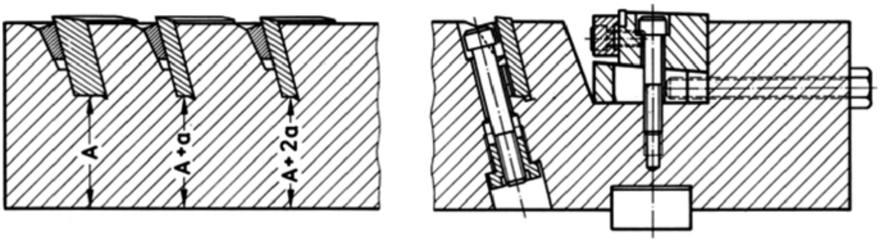

**Figure 12.14**
Mounting of the cemented carbide blades with a clamping wedge

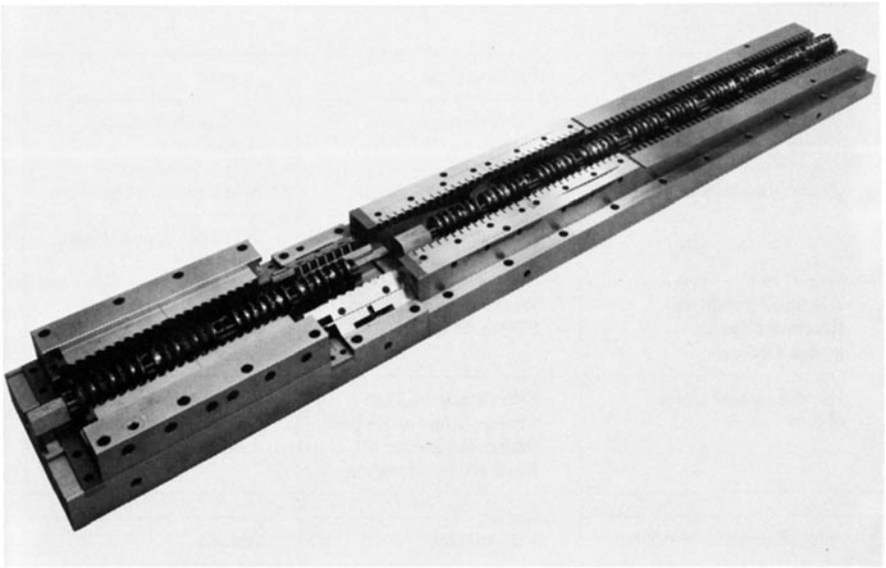

**Figure 12.15**
Broach tipped with cemented carbide blades
(*photo by Karl Klink, Niefern*)

**Figure 12.16**
Cutting portions with hard soldered cemented carbide tips
(*photo by Karl Klink, Niefern*)

## 12.8 Failures during broaching

**Table 12.7** Failures and corresponding reasons

| **12.8.1 Tool failure** | | |
|---|---|---|
| Consequence for the tool | Reason for the failure | Remedy |
| Tool cutting edge dulls prematurely | Tooth pitch too small | Select greater tool pitch |
| Teeth break off | Tooth space too small | Increase tooth space |
| | Form of tooth space does not conform to material | Change form of tooth space |
| Broach snaps out, fractured surface with rough structure | Tool was overheated during hardening | Check hardening procedures |
| Broaching machine stops | Tooth pitch too small<br>Too many teeth in contact<br>Broaching force greater than broaching stroke force of the machine | Increase tooth pitch<br>Decrease teeth offset |
| One surface on workpiece not exact | Internal broach (4-hedral) dull on one side | Regrind broach |
| Surfaces on the workpiece (internal broaching) machined unevenly | Workpiece clamping instable | Improve tightening |
| Outgoing side of an internally broached workpiece jammed | Tooth space too small | Increase tooth space |
| | Pitch too low | Increase tooth space |
| Hole with chatter marks | All teeth have identical pitch | Use tool with heterogeneous tooth pitch |

### 12.8.2 Workpiece failures

| Consequences for the workpiece | Reason for the failure | Remedy |
|---|---|---|
| Chatter marks with great distance between shafts | Rest of the workpiece not angular to the hole | Check rest |
| Workpiece inexact Jamming on the outgoing side of the workpiece | Soft marks in the workpiece material | Check workpiece material and change, if necessary |

## 12.9 Reference tables

**Table 12.8** Cutting speeds $v$ in m/min for broaching [52]

| Material | Internal broaching | External broaching |
|---|---|---|
| S 275 JR–E 335 | 4–6 | 8–10 |
| E 360 and slightly alloyed steels | 2–3 | 6–8 |
| Alloyed steels up to 1000 N/mm2 | 1,5–2 | 4–6 |
| Cast steel | 2–2,5 | 5–7 |
| Gray cast iron | 2–3 | 5–7 |
| Brass, bronze | 3–4 | 10–12 |
| Al alloys | 4–6 | 12–15 |

**Table 12.9** Reverse speed $v_r$ in m/min of the broaching machine

$$\boxed{v_r = 12 - 30 \text{ m/min}}$$

## 12.10 Calculation example

The task is to simultaneously generate 2 opposite grooves in a pulley made of E 360, hub length 100 mm (see sketch). An internal broach is to be used.

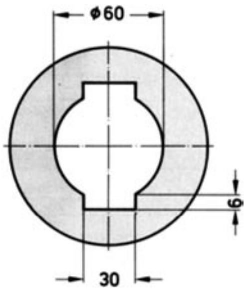

**Figure 12.17**
Pulley

*Given:*
Maximal broaching stroke force of the internal broaching machine $F_M = 200$ kN

*Sought:*

1. Tooth pitch
2. Tooth number for roughing and finishing
3. Length of the cutting portion
4. Number of teeth being in contact
5. Broaching force
6. Comparison of broaching force and machine pulling capacity
7. Machining time for one workpiece

*Approach:*

1. Tooth pitch

Tooth pitch is calculated according to the required chip space.

$$t_{\text{min}} = 3 \cdot \sqrt{l \cdot f_z \cdot C}$$

chip space number $C$ selected from Table 12.1: $C = 7$

$f_z = h$ is selected from offset table 77

$f_{z1} = h_1 = 0{,}1$ mm for roughing

$f_{z2} = h_2 = 0{,}02$ mm for finishing

Roughing:

$$t_{\text{min}_1} = 3 \cdot \sqrt{100 \text{ mm} \cdot 0{,}1 \text{ mm} \cdot 7} = 25{,}09 \text{ mm} \rightarrow 25 \text{ mm selected}$$

Finishing:

$$t_{\text{min}_2} = 3 \cdot \sqrt{100 \text{ mm} \cdot 0{,}02 \text{ mm} \cdot 7} = 11{,}22 \text{ mm} \rightarrow 11 \text{ mm selected}$$

2. Tooth numbers for roughing, finishing and calibrating

2.1. Five teeth are assumed for finishing

$z_2 = 5$ teeth

2.2. For roughing

$$z_1 = \frac{h_{\text{ges}} - 5 \cdot f_{z2}}{f_{z1}}$$

Groove depth is 6 mm. It corresponds to allowance $h_{\text{ges}}$

$$z_1 = \frac{6 \text{ mm} - 5 \cdot 0{,}02 \text{ mm}}{0{,}1 \text{ mm}} = 59 \text{ teeth}$$

2.3. For calibrating, 5 teeth are assumed

$z_3 = 5$ teeth

For calibrating, the same pitch as for finishing is selected.

3. Length of the broach's cutting portion $a_2$

$a_2 = t_1 \cdot z_1 + t_2 \cdot (z_2 + z_3)$

$a_2 = 22 \text{ mm} \cdot 59 + 11 \text{ mm} \cdot (5 + 5) = 1408 \text{ mm}$

4. Number of teeth in contact

Since the maximal force appears for roughing, pitch for roughing is used to determine $z_E$.

$$z_E = \frac{l}{t} = \frac{100\,\text{mm}}{25\,\text{mm}} = 4 \text{ teeth}$$

5. Broaching force

5.1. Specific cutting force

$$k_c = \frac{(1\text{ mm})^z}{f_z^z} \cdot k_{c1,1} \cdot K_v \cdot K_{st} \cdot K_{ver} \cdot K_\gamma$$

$K_v = 1{,}15$; $K_{st} = 1{,}1$; $K_{ver} = 1{,}3$

$$K_\gamma = 1 - \frac{15^\circ - 6^\circ}{100} = 0{,}91$$

$k_{c1,1}$ from Table 1.1 and $\gamma_{tat} = 15°$ from Table 12.2

$$k_c = \frac{(1\text{ mm})^{0,3}}{(0{,}1\text{ mm})^{0,3}} \cdot 2260\text{ N/mm}^2 \cdot 1{,}15 \cdot 1{,}1 \cdot 1{,}3 \cdot 0{,}91$$

$k_c = 6764{,}1\text{ N/mm}^2$

5.2. Major cutting force

Since 2 grooves are broached at the same time, $F_s$ has to be multiplied with factor 2

$F_c = a_p \cdot f_{z1} \cdot k_c \cdot z_E \cdot 2$

$F_c = 30\text{ mm} \cdot 0{,}1\text{ mm} \cdot 6764{,}1\text{ mm}^2 \cdot 4 \cdot 2 = 162338{,}4\text{ N}$

$F_c = 162{,}3\text{ kN}$

6. Comparison of broaching force $F_c$ and machine pulling capacity $F_M$

$F_M > F_c$

200 kN > 162 kN

Since the machine pulling capacity $F_M$ is greater than the required broaching force, the machine can be used for this job.

7. Confirmatory calculation of the load due to broaching stroke on the endangered broach cross-section

$d_R = 38\text{ mm}$ (DIN 1415)

$$A_0 = \frac{\pi}{4} \cdot d_R^2 = \frac{\pi}{4} \cdot 38^2\text{ mm}^2 = 1134\text{ mm}^2$$

$$\sigma = \frac{F_s}{A_0} = \frac{162 \cdot 10^3\text{ N}}{1134\,\text{mm}^2} = 142{,}8\,\text{N/mm}^2$$

$\sigma_{zul} = 250\text{ N/mm}^2$ for high speed steel

$\sigma < \sigma_{zul}$. For this reason, the work can be performed with this broach from the perspective of the broaching tool.

8. Machining time

8.1. Working stroke for internal broaching

$H = 1{,}2 \cdot l + a_2 + a_3 + l_2$
$l_2 = 125\text{ mm}$ from Table 12.6
$a_3 = 40\text{ mm}$ assumed

$a_2$ = 1408 mm calculated under 3.
$l$ = 100 mm hub length given in this task
$H$ = 1,2 · 100 mm + 1408 mm + 40 mm + 125 mm = 1693 mm

8.2. Machining time

$$v_\mathrm{c} = \frac{H(v_\mathrm{c} + v_\mathrm{r})}{v_\mathrm{c} \cdot v_\mathrm{r}}$$

$v_\mathrm{c}$ = 3 m/min selected from Table 12.8

$v_\mathrm{r}$ = 20 m/min assumed (see Table12.9)

$$t_\mathrm{h} = \frac{1{,}693\,\mathrm{m}\cdot (3\,\mathrm{m/min} + 20\,\mathrm{m/min})}{3\,\mathrm{m/min} \cdot 20\,\mathrm{m/min}} = 0{,}65$$

The CD-ROM attached to this book shows a practical example of machining a keyway by broaching in the lab of the University of Applied Sciences HTW Dresden and broaching of a Christmas tree-like profile to attach turbine blades.