Chapter 1
Introduction to the Technology of Cutting and Abrasive Processes

1.1 Economic Relevance

It stands to reason that manufacturing and assembly play an essential role in the industrial production process: They represent the transfer of planned products into real products by the fabrication of components, units and aggregates. Manufacturing processes can be divided into six main groups [TÖN94, DIN8580]:

- primary shaping
- forming
- separating
- joining
- coating
- changing material properties.

Cutting and abrasive processes are part of the main group of separation processes. They are mainly used for metallic materials and are fundamental steps in the production processes in machine and vehicle manufacturing, in the aerospace industry, in equipment and drive technology, in biomedical engineering and in many other industrial sectors. They provide an unsurpassed range of options for adapting qualities and shapes as well as the productivity. Compared to related, partly competing manufacturing processes like casting and forging, they stand out due to the large range of producible designs and shapes as well as their high accuracy. However, they are inferior to these processes regarding efficiency and productivity, i.e., the number of parts produced per unit time, at least in the production of larger quantities. Furthermore, in cutting and abrasive processes chips are removed from a workpiece, which includes material loss; therefore, cutting and abrasive processes are also inferior regarding sustainability, i.e., stewardship of energy and material resources. Figure 1.1 shows a rough qualitative comparison of cutting and abrasive processes with casting and forging.

Cutting and abrasive processes provide accuracies within the ISO tolerance grades of IT2 to IT10. They are used for the individual production of single pieces or small numbers of pieces, e.g., for the production of customized endoprostheses;

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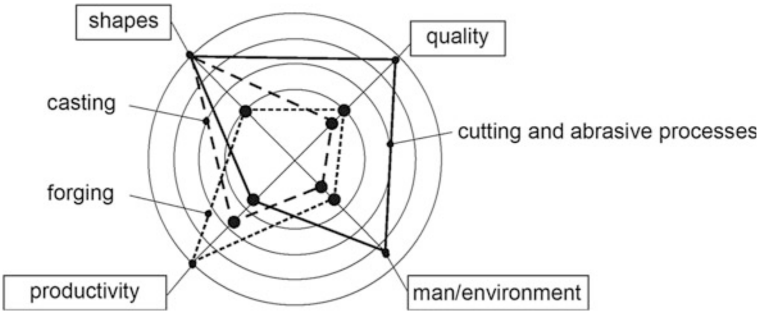


Fig. 1.1 Comparison of three manufacturing processes

for the production of small or medium series, e.g., for racing vehicle engine components and for mass production, e.g., in automotive engineering. Because they provide high accuracies, they are often placed at the end of a sequence of several manufacturing processes, which means that additional emphasis has to be put on the process reliability. As mentioned above, cutting and abrasive processes can be used to produce a nearly unlimited variety of shapes. This is mainly due to the fact that they are generating (in the sense of kinematically controlled) processes (in contrast to copying processes): the necessary tool geometry is independent from the final shape of the product. In other words, the product is not an image of the tool shape, but its shape is produced by a controlled movement and interaction between the tool and the workpiece (Fig. 1.2). This means that the movement of the tool can be directly computer-controlled using path variables.

This provides high flexibility: Different components can be produced within a continuous sequence or clamping and a lot size of 1 is feasible.

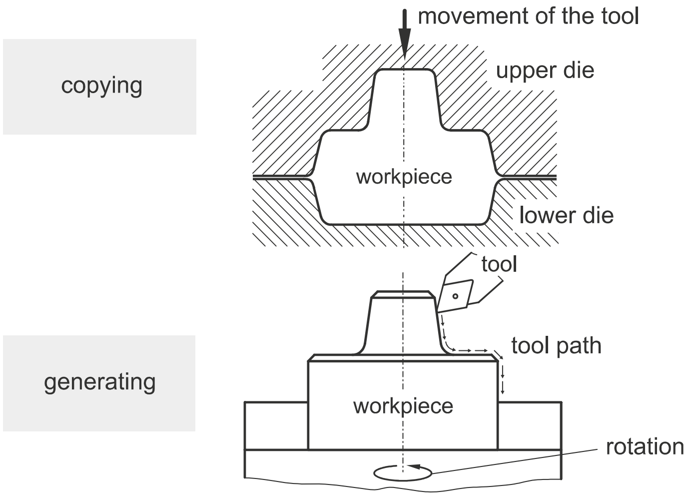


Fig. 1.2 The principless of copying and generating

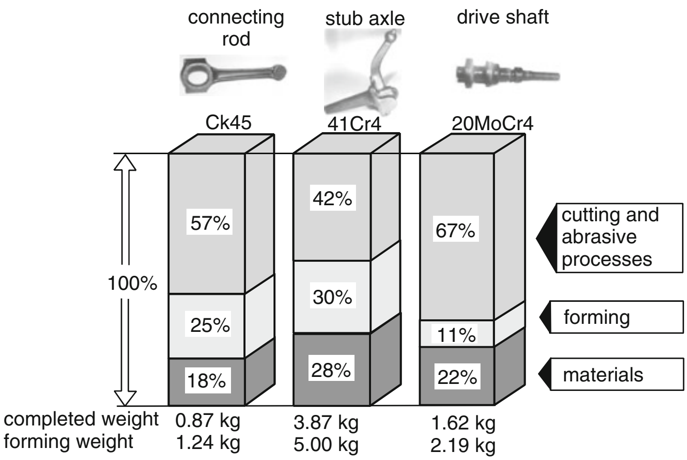


Fig. 1.3 Manufacturing cost structure of selected power train components [TÖN10]

Figure 1.3 shows that cutting and abrasive processes are of decisive relevance in serial production, e.g., in automotive engineering.

1.2 Taxonomy

Cutting and abrasive processes represent manufacturing by means of material separation, particularly of material removal. Material in the form of chips is mechanically removed from a raw part/workpiece by one cutting edge (in turning), several cutting edges (in milling) or numerous cutting edges (in grinding). In *cutting processes*, the number of cutting edges, the shape of the cutting edges and their position in relation to the workpiece are known and describable (Fig. 1.4). In contrast, in *abrasive processes*, only statistical parameters are known regarding the geometry and the number of the cutting edges in the abrasive material.

According to the most comprehensive taxonomy of cutting and abrasive processes [TÖN94b, CIRP04, DIN8589-0], the groups of cutting processes respectively abrasive processes can first be further divided regarding the specific process (1st digit: separation, 2nd digit: cutting, abrasive processes, 3rd digit: e.g., turning, milling), and then according to

- the geometry of the surface to be produced (4th digit: plain/slab, cylindrical/circular, thread/helical, hobbing, profile, form)[1]
- the feed direction (5th: orthogonal, longitudinal) or tool characteristics
- the position of the surface to be produced (6th digit: external, internal)

Typical examples of turning processes are presented in Fig. 1.5.

[1] With the exceptions of tapping (for thread drilling) and hobbing (for gear milling).

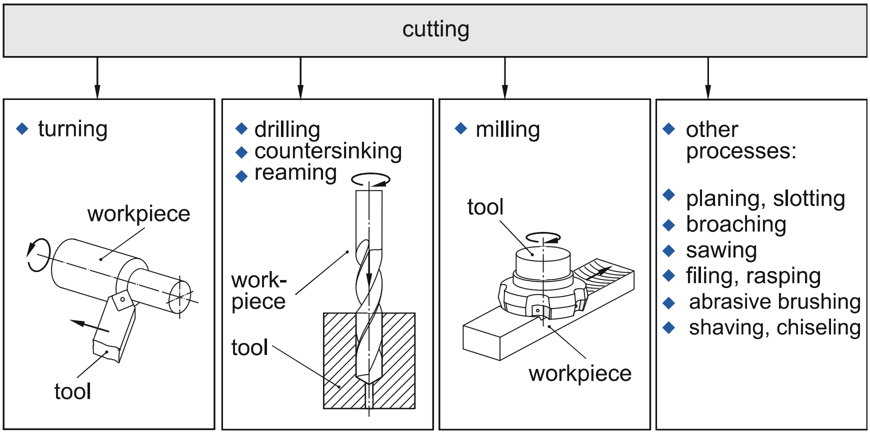


Fig. 1.4 Manufacturing processes: cutting [TÖN94b, CIRP04, DIN8589-0]

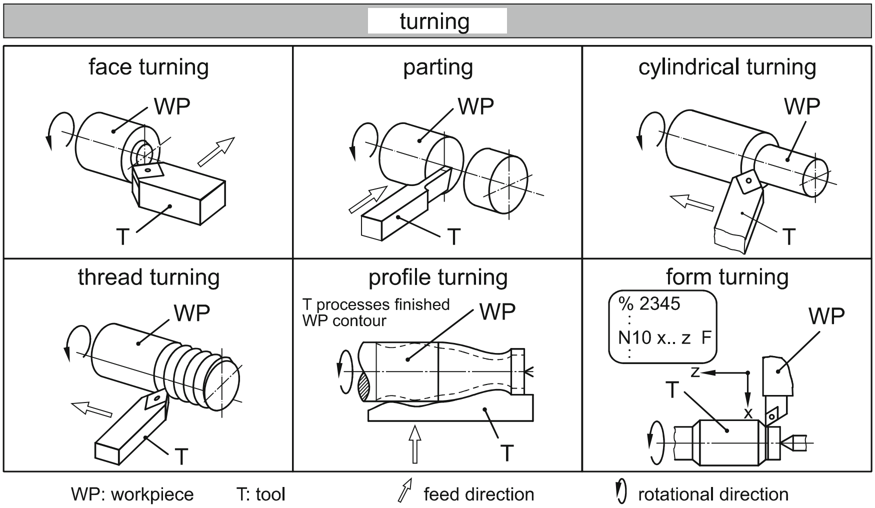


Fig. 1.5 Turning processes [TÖN94c, DIN8589-1]

1.3 Motions, Angles at the Cutting Edge and Engagement Parameters

In cutting processes, a cutting edge penetrates into the workpiece material. The relative movement between the tool and the workpiece can be described by means of the primary motion (cutting motion) with the cutting speed v_c and the feed motion with the feed speed v_f (Fig. 1.6). The depth of cut and the feed speed determine the cross-section of the undeformed chip A.

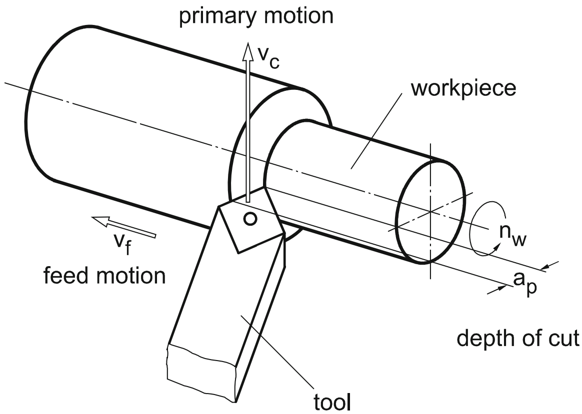


Fig. 1.6 Motions in cutting processes (In all presented figures, speed arrows are assigned to the tool (independently from the real actions in the process), thus pretending that the workpiece is fixed in position and that the tool performs all motions. In most real turning processes (but by no means all), the tool performs the feed motion while the workpiece performs the rotary motion)

The vectors of the feed speed and the cutting speed span the working plane (Fig. 1.7). The vectorial sum of the cutting speed and the feed speed is the effective cutting speed v_e. The cutting speed and the effective cutting speed form the effective cutting speed angle η. The cutting speed and the feed speed form the feed motion angle φ. In turning and drilling (in all processes with a helical or linear effective cutting motion) η and φ are constant ($\varphi = 90°$), while in milling,

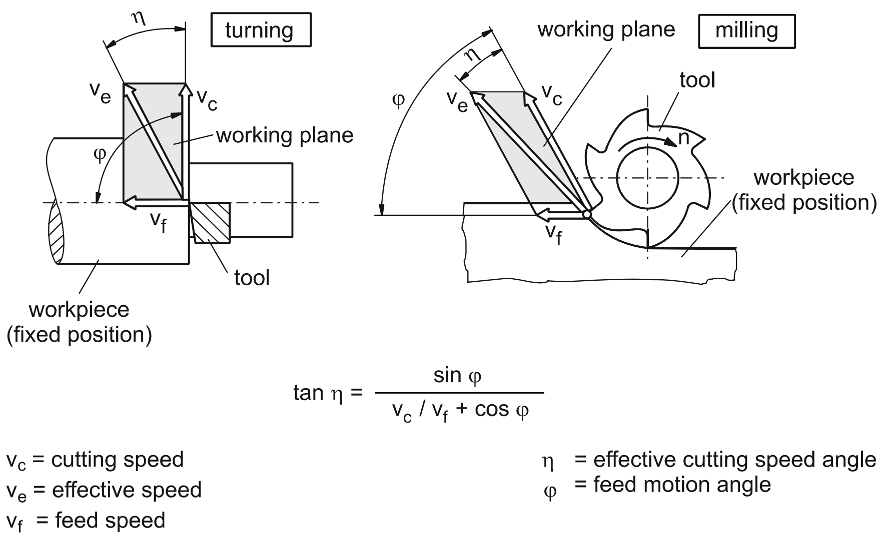


Fig. 1.7 Effective cutting direction in the working plane in cylindrical turning and peripheral milling

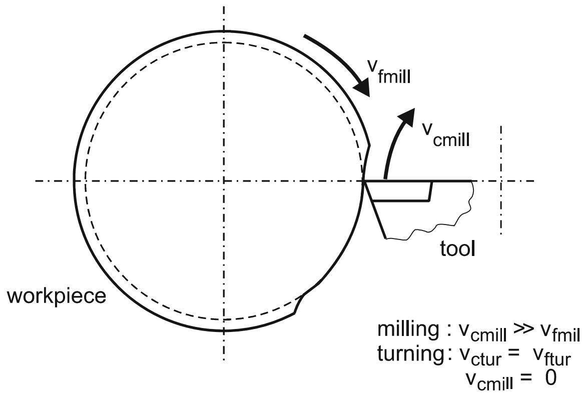


Fig. 1.8 Turning as a special case of milling (To illustrate this point, the speed arrows have for once been assigned to the workpiece)

circular sawing and grinding (in all processes with a cycloidal effective cutting motion) they are variable and time-dependent.

In all processes with a constant feed motion angle of $\varphi = 90°$ (turning, drilling, broaching), i.e., all processes with a linear, helical or spiral effective cutting motion, the material removal rate Q_w (the volume of material removed per unit time) is

$$Q_w = a_p \cdot f \cdot v_c, \tag{1.1}$$

while in processes with a time-dependent feed motion angle (milling, grinding, circular sawing), it is

$$Q_w = a_p \cdot a_e \cdot v_f. \tag{1.2}$$

It might be surprising that (according to Eq. 1.1) the material removal rate for turning processes is calculated using the cutting speed, whereas according to Eq. 1.2, the feed speed is used for milling processes. Figure 1.8 illustrates that turning can be regarded as a special case of milling and consequently with a fixed tool, the primary motion actually is a feed motion.

The relevant angles at the cutting edge are located within different planes. In the tool orthogonal plane (i.e., the plane orthogonal to the tool reference plane and the cutting edge plane), these are the clearance α ($\alpha > 0$ in every case), the rake angle γ ($\gamma > 0$ if the tool tip is preceding) and the wedge angle $\beta = 90° - (\alpha + \gamma)$. In the cutting edge plane the relevant angle is the tool cutting edge inclination λ ($\lambda > 0$ if the tool tip is proceeding). The tool cutting edge angle κ and the tool included angle ε are located in the tool reference plane (Fig.1.9). The cutting edge itself is defined by the corner radius r_ε, measured in the tool reference plane and by the cutting edge rounding, measured in the tool orthogonal plane using the cutting edge radius r_β.

The undeformed chip cross section A can be described using two different systems of parameters: either by coordinates derived from the relative movement between the tool and the workpiece, i.e., the engagement parameters a_p (depth of

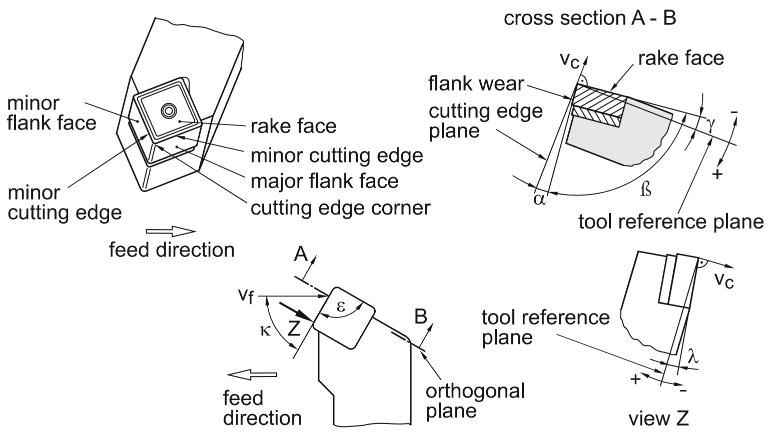


Fig. 1.9 Terminology for turning tools [ISO3002-1, ISO3002-3, DIN6581]

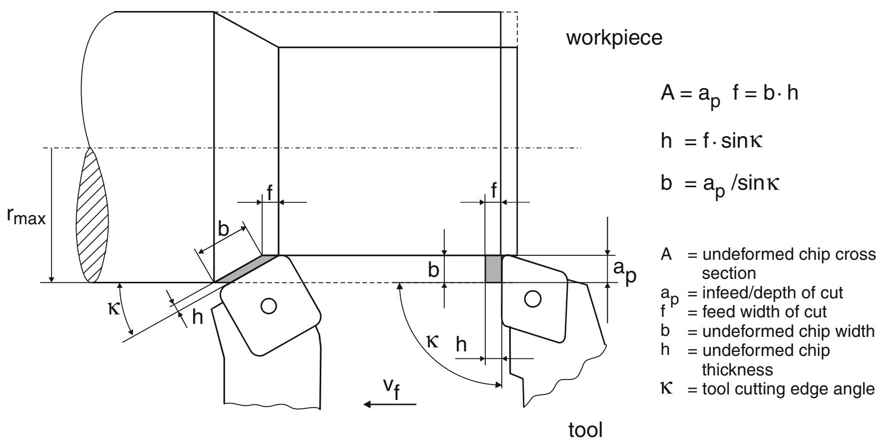


Fig. 1.10 Turning: engagement parameters and undeformed chip parameters

cut) and a_e (width of cut), in practice called the infeed a_p and the feed $f = a_e$, or by the essential parameters in the chip formation process, i.e., the undeformed chip parameters b and h (Fig. 1.10).

The feed is determined using the rotational speed of the workpiece n_W:

$$f = \frac{v_f}{n_w}. \tag{1.3}$$

The cutting speed v_c is usually indicated for the maximum contact diameter $2 \cdot r_{max}$:

$$v_c = 2\pi \cdot r_{\max} \cdot n_w. \tag{1.4}$$

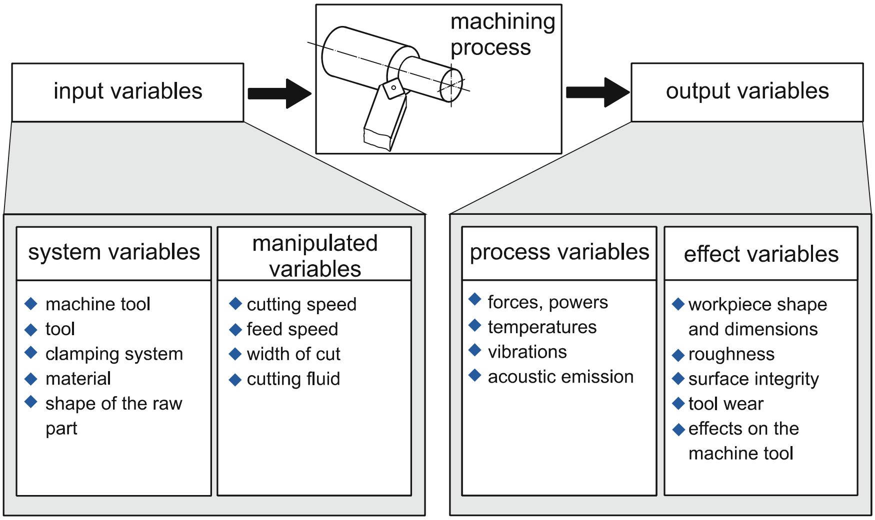


Fig. 1.11 Cutting and abrasive processes as a black box system

1.4 Cutting and Abrasive Processes as Black Box Systems

From a system-oriented point of view, cutting and abrasive processes can be described as black boxes with input variables and output variables (Fig. 1.11). The input variables can be divided into system variables and manipulated variables (set variables). System variables describe process conditions which are either completely fixed or at least constant over a relatively long period of time. They depend on the machine tool (static and dynamic stiffness, temperature response), the workpiece (strength, shape of the raw part, chemical composition, structure) and the tool (material, shape, mechanical properties) (Fig. 1.11).

The manipulated variables or set variables for each workpiece or job order are usually assessed and adjusted manually or using a program memory. They include the rotational speed or cutting speed, feed speed (depth of cut) and width of cut (infeed of the tool towards the workpiece). Furthermore, they can include the cutting liquid supply and the clamping force applied to fix the workpiece.

The output variables are divided into process and effect variables. Process variables like resultant forces, powers, temperatures in the chip formation zone, vibrations caused by the process and acoustic emissions are only perceivable during the actual process. They can be used for monitoring or diagnosing purposes [TÖN01]. Effect variables can be measured at the workpiece (deviations in dimension, shape and position, micro-geometry, influence on the external surface zone), at the tool (wear), at the machine tool (temperature rise, wear) and in the cutting fluids (temperature rise, contamination and chemical properties).

In the process the input variables are converted into output variables. The transmission behavior of the process can be characterized by a comparison of the input and output variables. The following four criteria are used for evaluating a process and define the machinability:

- resultant force
- tool wear
- surface properties of the workpiece
- chip form.

It is assumed that the input variables are predetermined, because the main technology and the productivity (e.g., the material removal rate) are determined by the process, the machine tool and the corresponding movement control [TÖN94a].

The *resultant forces* influence

- the design of the machine tool drives
- the design of the machine tool frame, respectively the deformation of the machine tool frame
- the power requirement
- the elastic deformation of the workpiece and the tool
- the requirements on the clamping systems for the workpiece and the tool.

The *tool wear* has a crucial influence on the economic efficiency of the process. The deviation of the *surface properties* from the ideal target values (dimensions, shape, position, roughness, physical properties of the external zone) determines the workpiece quality. The *chip form* is important for the tool design (flutes or gullets for chip removal), for the design of the working space of the machine tool and for an disturbance-free process (process reliability).

1.5 Process Types and Engagement Parameters in Drilling

Drilling is a cutting process with a rotational primary motion. Common drilling processes are shown in Fig. 1.12. The tools usually have a complex design. The following general characteristics of drilling processes can make their use problematic:

- The cutting speed is dependent on the radius, i.e., it is proportional to the radius from the axis of rotation of the drill and has a value of zero at the axis itself. As a result, no material separation can take place at this part of the drill. This influences the necessary forces and torques.
- Chips have to be removed from the drilled hole. The respective travel distance increases with the drilling depth, which can cause problems in the chip removal.
- The supply of cutting liquid also becomes increasingly difficult with an increase in the drilling depth, which sometimes makes additional measures necessary (internal cutting liquid supply).
- Drilling tools can only produce holes of fixed dimensions, so that the drilling diameter cannot be adjusted by means of the process control.

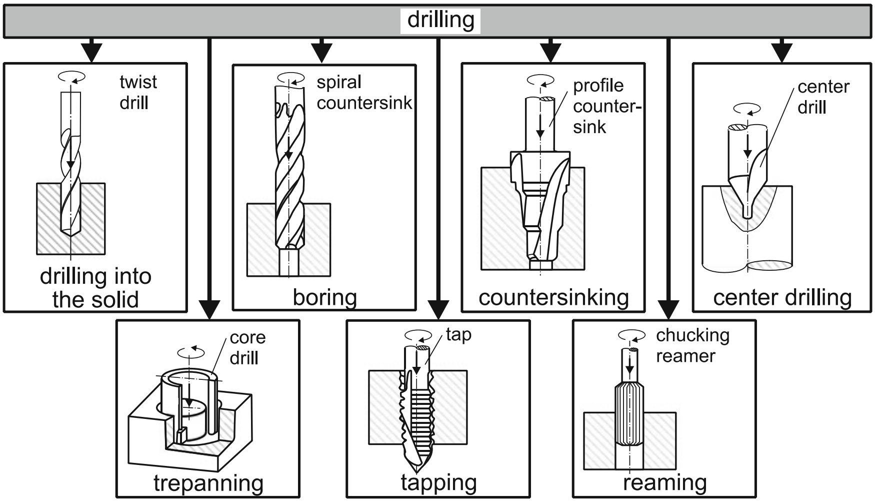


Fig. 1.12 Drilling processes [DIN8589-2]

In the following, two technological parameters that make up essential manipulated variables will be defined using the example of drilling processes: the cutting speed v_c and the feed per cutting edge f_z. They are each limited by a characteristic process limit. The cutting speed is limited due to the thermal load and thus by the wear behavior of the tool, while the feed per cutting edge is limited due to the mechanical load. The derived manipulated variables like the rotational speed n_t with the drilling radius r and the feed speed v_f with the cutting edge number z depend on these technological parameters as follows:

$$n_t = v_c / (2 \cdot \pi \cdot r) \tag{1.5}$$

$$v_f = z \cdot f_z \cdot n_t \tag{1.6}$$

In general, a twist drill with z = 2 is used for *drilling from the solid.* The material removal rate in drilling from the solid is

$$Q_w = \frac{1}{2} r \cdot f \cdot v_c \tag{1.7}$$

with the feed f of the drill:

$$f = z \cdot f_z \tag{1.8}$$

The twist drill consists of a shank (cylindrical or conical) and a cutting part. The terminology for drills, the engagement parameters and the angles at the cutting edges are illustrated in Fig. 1.13. The drill is clamped and guided by the shank. As a result the shank particularly serves the purpose of torque transmission. By means of the complex cutting edge geometries of the different drills, the tool can be adapted to each specific drilling task. On the one hand, the profile of the twist drill

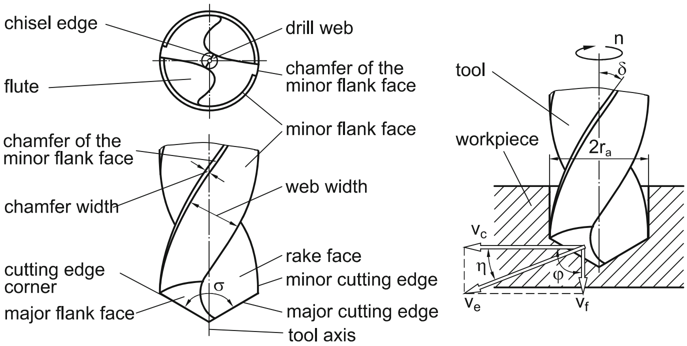


Fig. 1.13 Terminology and mode of the operation of a twist drill [DIN8589-2]

has to possess large flutes in order to provide sufficient space for chip removal; on the other hand, the drill must exhibit appropriate torsional rigidity (polar moment of inertia) and torsional strength (shear modulus). The helix angle δ of the flutes influences both the chip removal and the rake angle at the cutting edges.

The rake angle at the drill has an essential influence on the deformation and the forces at the cutting edges. We distinguish between the rake angle at the chisel edge γ_q, which can by all means be highly negative due to geometrical reasons and the rake angle at the major cutting edge γ_h (Fig. 1.14).

Near the center of the drill, γ_q is $-\sigma/2$. Further along the chisel edge it rises slightly but remains within the range of

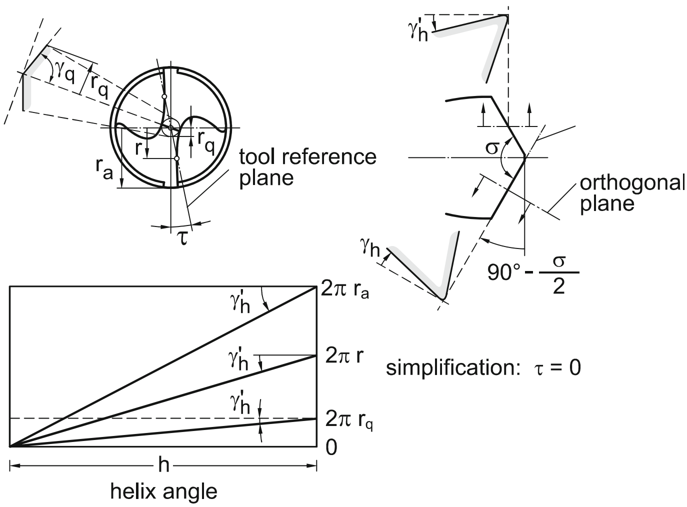


Fig. 1.14 Rake angle at the drill

$$-\frac{\sigma}{2} \leq \gamma_q \leq -\left(1 - \frac{r_q}{r_a}\right) \cdot \frac{\sigma}{2}. \quad (1.9)$$

At the outer perimeter of the drill ($r = r_a$), the rake angle at the major cutting edge is the helix angle corrected by the drill-point angle σ:

$$\gamma_h(r = r_a) = \arctan \frac{\tan \delta}{\sin \sigma/2}. \quad (1.10)$$

Towards the axis of rotation, it changes with the radius (Fig. 1.10):

$$\gamma_h = \arctan\left(\frac{r}{r_a} \frac{\tan \delta}{\sin \sigma/2}\right). \quad (1.11)$$

Figure 1.15 illustrates the significant change in the rake angle along the radius of the drill, by means of a cross-section through the chip formation zone in front of the cutting edges.

The drill-point shape of the twist drill has an essential influence on the cutting ability, because it determines the clearance angle. Attention has to be paid to the fact that the ratio of the feed speed to the cutting speed and thus the effective cutting speed angle η along the cutting edges, vary with the drill radius (Fig. 1.14).

Taking this speed ratio into account, the clearance angle has to be increased—if only for kinematic reasons—in order to avoid pressure generation (for a detailed derivation, see Sect. 7.1). Because the cutting edge is inclined by a lead angle of $\kappa = -\sigma/2$, the minimum clearance angle α_{min} can be calculated regardless of elastic flattening as:

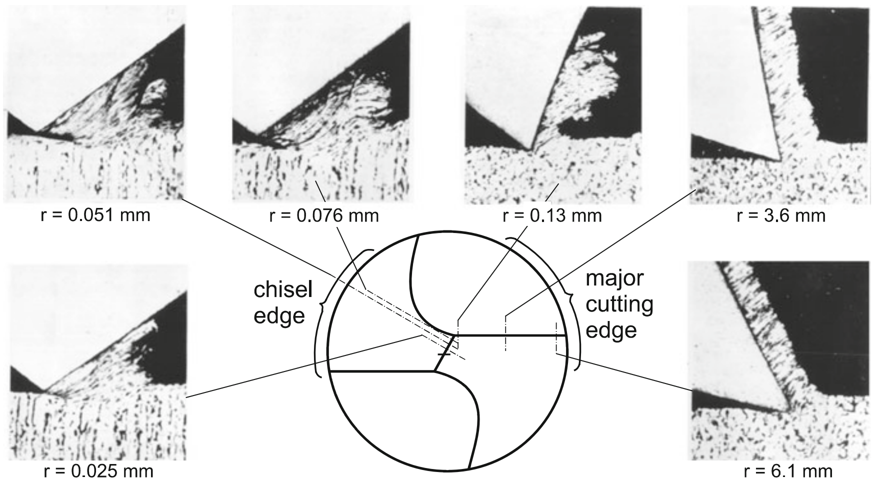


Fig. 1.15 Chip formation in drilling from the solid

$$\tan \alpha_{\min} = \frac{v_f}{v_c} \cdot \sin \frac{\sigma}{2} = \frac{f \cdot \sin \frac{\sigma}{2}}{2\pi \cdot r}, \tag{1.12}$$

assuming that the cutting edge is not preceding ($\tau = 0$).

Vice versa, if the minimum clearance angle at the outer radius of the web r_q is given, the maximum permitted feed across the radius $f_{max}/2r_a$ can be calculated as

$$\frac{f_{\max}}{2r_a} = \frac{\pi \cdot \tan \alpha_{\min}}{\sin \frac{\sigma}{2}} \cdot \frac{r_q}{r_a}. \tag{1.13}$$

With common values ($\sigma = 118°$, $r_q/r_a = 0.2$) and assuming a minimum clearance angle of $\alpha_{min} = 2°$, the maximum permitted feed related to the outer diameter is $f_{max}/2r_a = 0.026$. Considering flattening and wear, the value used in the process should never exceed half this calculated value.

The drill-point is ground considering the following conditions:

- The drill should have appropriate centering properties.
- The clearance angle should be adequately large along the whole length of the cutting edge.
- However, the cutting edge should be as stable as possible.
- The chisel edge should be as short as possible because of the disadvantageous chip formation processes.

The most common drill-point shape for HSS twist drills is the conical point. It is produced by grinding the drill using a grinding face, revolving the drill around an axis that is inclined by a certain angle towards its center axis, e.g., with a tilt angle of 20°. The clearance angle is thus part of a cone surface. It increases towards the axis of rotation. The conical point can be ground using a simple kinematic process on a point grinding machine.

There is also a range of special drill-point shapes which are partly standardized (DIN1412) and partly manufacturer-specific. Depending on the specific application, particular significance is attached to one of the conditions mentioned above. Some special drill-point shapes are presented in Fig. 1.16.

To produce shape A the chisel edge is reduced to about half its initial length by web thinning, with the shape of the thinned chisel edge adjusted to the flute profile. The shortening of the chisel edge reduces the feed forces, while it has almost no influence on the torque.

To produce shape B out of shape A, the rake angle is corrected at the major cutting edges. Thus, the rake angle is no longer dependent on the helix angle of the flutes. Such corrections can increase the stability of the cutting edges and have a positive effect on the chip form.

The split point (shape C) can be regarded as a special kind of web thinned point. The length of the chisel edge is reduced to about 6 % of the outer radius. Hence, even positive rake angles can be produced at the chisel edge.

In *boring out and countersinking* processes, a previously produced hole is enlarged. It is difficult to guide the tool on a coaxial path, because there is no

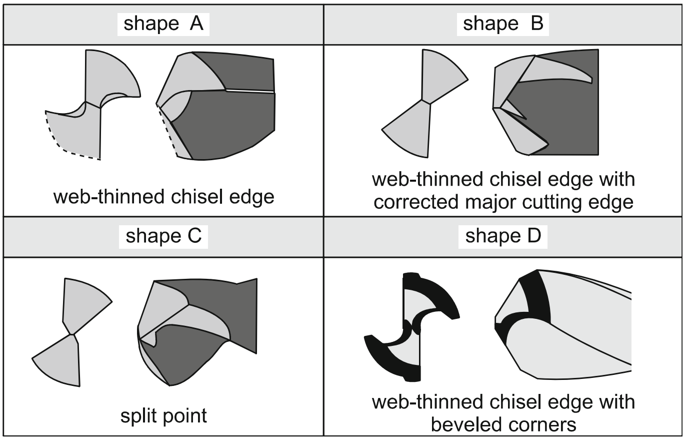


Fig. 1.16 Common drill-point shapes [DIN1412]

center point in the workpiece material, so the tools generally have three or multiple cutting edges. However, chip removal is easier than in drilling from the solid. Therefore, bore holes with a high diameter are often predrilled using a smaller twist drill and then enlarged within several steps, until they reach the nominal diameter. This procedure is also called for, if the maximum permitted feed force, respectively the maximum permitted torque of a machine are not sufficient to drill the hole within one stroke. The material removal rate in drill out processes with the inner radius r_i is

$$Q_w = \frac{1}{2}\left(r - \frac{r_i^2}{r}\right) \cdot f \cdot v_c \qquad (1.14)$$

Center drilling is necessary, if the surface to be drilled is rough, uneven or inclined. It can be avoided by using a very stiff guidance for the drill (drill clamped with a short projecting length, stiff spindle) or by using drill bushings.

Trepanning is used for large bore hole diameters. An annular cut is produced instead of cutting the whole bore diameter. This reduces the required torque and power. However, trepanning can only be used for through holes.

Tapping is used to produce internal threads. The tap feed must be adjusted to the thread pitch. In machine production, this can be achieved by exact guidance using an NC machine tool or by first using a starting taper and then a tap holder. The rotational direction has to be reversed to remove the drill from the hole. If multi spindle bar machines are used, special devices are needed for this purpose (disconnecting the spindle and reversing the rotational direction or using a second spindle which is attached to the tool and outruns the workpiece spindle). To avoid having to reverse the rotational direction, large internal threads can be produced by thread chasing, which is profile turning within several strokes. This can also be done using controllable collapsible taps.

Reaming is a finishing process corresponding to a boring out process with a multiple edged tool and a small depth of cut. It is used for bore holes with high dimension and shape accuracy. The position accuracy cannot be influenced. Tolerance grades of IT 7—with an increased effort even IT 6—can be achieved. The surface roughness R_z is about 5 µm. Conventional HSS reamers are used at low cutting speeds of 10–20 m/min and low feed rates of 0.08–1.25 mm. If clocked automated systems are used, this kind of reaming has a significant influence on the clock cycle. Therefore, alternative processes and tools have been developed.

1.6 Process Types and Engagement Parameters in Milling

In *milling*, the necessary relative movement between the tool and the workpiece is achieved by a rotational cutting motion of the tool and a feed motion orthogonal or at a certain angle to the rotational axis of the tool. The feed motion can be performed by the tool or the workpiece or by a combined movement of the two. The cutting edges are not permanently engaged. The feed motion angle and the effective cutting speed angle are time-dependent (see Sect. 1.3). The most important milling processes are shown in Fig. 1.17. They are classified according to the produced shapes, which are determined by the feed motion. In *face milling* the rotation axis of the tool is orthogonal to the produced surface, while in *peripheral milling* it is parallel to the surface. *Side milling* is a combination of these two processes and is used to produce two surfaces that are orthogonal to each other. *Helical milling* and *hobbing* produce helical or gear surfaces. In *profile*

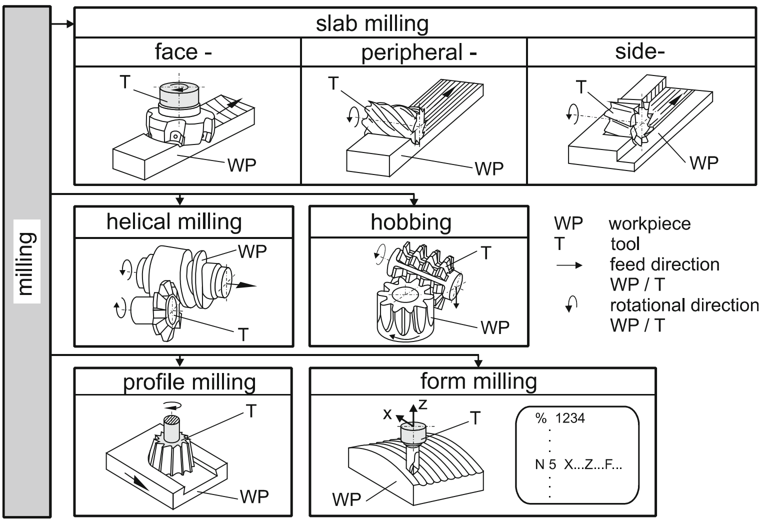


Fig. 1.17 Milling processes [DIN8589-3]

milling the tool shape is reproduced on the workpiece, making its shape and dimensions dependent on those of the tool. The largest variety of shapes can be produced by *form milling*, even though the range of producible shapes depends on the number of controllable feed axes on the milling machine. A milling machine usually possesses three linear feed axes, which can be controlled both simultaneously and independently (continuous path control), enabling the tool to follow any three-dimensional path. In special machines, two rotational axes are added to these three linear axes (five axes milling), so that the rotational axis of the milling cutter can be positioned in any direction at any point of the path.

If we focus on the productivity of the milling process in *roughing* processes, i.e., on removing large volumes of workpiece material as fast as possible, we have to determine the material removal rate Q_w:

$$Q_w = a_p \cdot a_e \cdot v_f \tag{1.15}$$

If we want to cut a large surface by a *finishing* process, the productivity is determined using the area cut per time unit $\dot{A}_w$ (applicable for face milling; for peripheral milling, a_e is replaced by a_p):

$$\dot{A}_w = a_e \cdot v_f \tag{1.16}$$

At any point of time each cutting edge of the milling cutter is engaged by a maximum of 180° or less, leading to an interrupted cut. The chips produced in the process are comma-shaped. The engagement parameters are dependent on the penetration angle/feed motion angle φ (Fig. 1.18).

The milling process is often characterized using the mean chip thickness h_m. It is the average chip thickness across the engagement path.

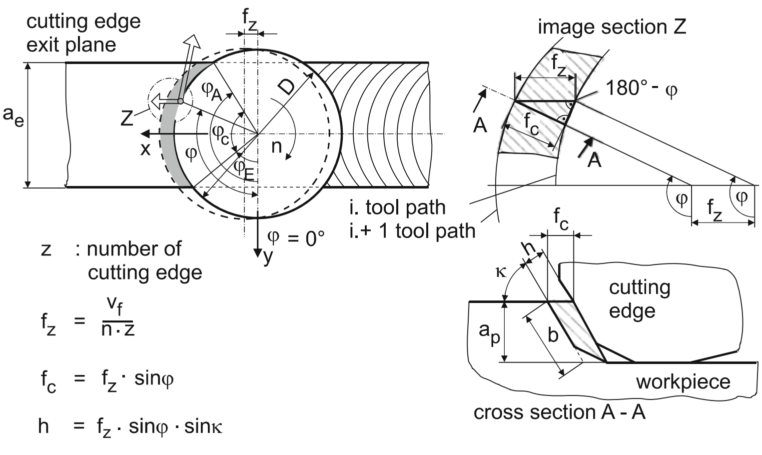


Fig. 1.18 Engagement parameters in face milling

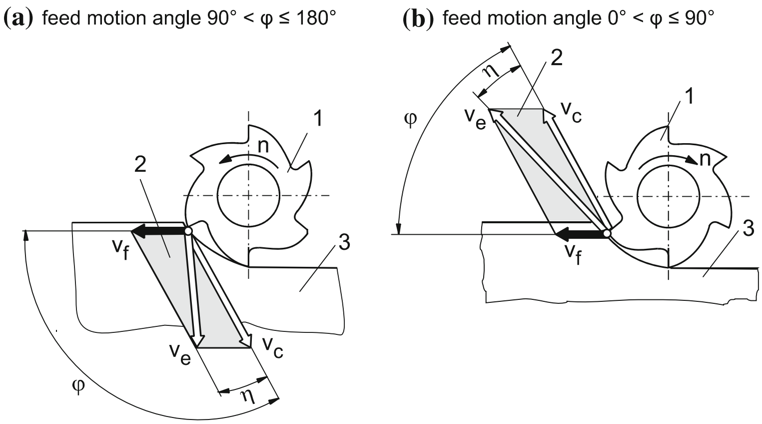


Fig. 1.19 Down milling **a** and up milling **b**

$$h_m = \frac{1}{\varphi_c} \cdot \int_{\varphi_E}^{\varphi_A} h_{(\varphi)} d\varphi = \frac{1}{\varphi_c} \cdot f_z \sin\kappa \left(\cos\varphi_E - \cos\varphi_A\right) \tag{1.17}$$

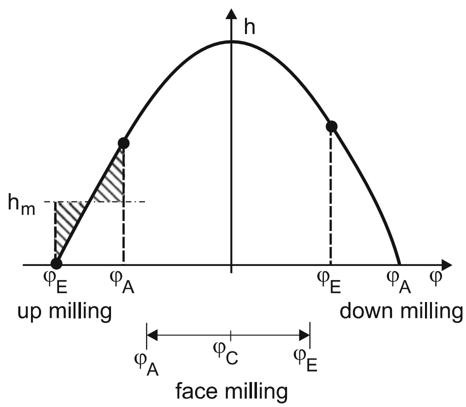
where

$$\left(\cos\varphi_A - \cos\varphi_E\right) = 2a_e/D \tag{1.18}$$

According to the approach type, we distinguish between down milling and up milling (Figs. 1.19, 1.20).

In the down milling process, the cutting edge enters the workpiece at the thicker end of the comma-shaped chip and builds up a shock-type resultant force. Therefore, the machine tool must exhibit appropriate dynamic stiffness (against vibrations). In the up milling process, the chip formation starts at the thinner end, thus pressure forming takes place at the beginning. This results in unfavorable chip

Fig. 1.20 Chip thickness in milling processes



formation conditions, because the chip thickness is below the minimum value in the beginning and instead of chip formation only high normal forces and friction forces occur, leading to an increased wear compared to that in the down milling process. If the machine tool and the workpiece allow for it, down milling should be used. In particular, the machine tool must not allow for any backlash in the feed drive—a condition which is met by all modern NC machine tools anyway. In down milling, one force component is orthogonal to the produced surface and thus the workpiece is automatically pressed against the supporting surface. This also makes down milling convenient for the cutting of long, slender workpieces, which, in up milling would be pulled away from the supporting surface. In face milling, the process mode changes between up and down milling, depending on the position of the rotation axis towards the workpiece, as illustrated in Fig. 1.18.

According to Eq. 1.17, the mean chip thickness is calculated as the average value of the chip thickness across the engagement path. In literature this is simplified by using the value of the chip thickness across the average value of the engagement path. Equation 1.17 shows that the relation between the path and the chip thickness is nonlinear. Thus these two definitions are not identical. However, there is only a slight difference in the calculated chip thickness for both up and down milling.

1.7 Questions

1. Give a taxonomy of all manufacturing processes and of the cutting and abrasive processes. Which classification criteria have been applied?
2. Assess the manufacturing processes of casting, forging and cutting/abrasive processes with regard to different aspects.
3. Which values can be used to determine the efficiency of the processes of roughing and finishing?
4. Why do we use different parameters for calculating the material removal rate in turning and in milling?
5. What are the process limits of finishing processes?
6. What are the process limits of roughing processes?
7. What is the difference between the effective cutting speed angle and the feed motion angle in turning and drilling on the one hand and milling on the other hand?
8. How can we determine the material removal rates of different drilling processes?
9. Give the definition of the terms “tool reference plane”, “cutting edge plane” and “tool orthogonal plane”.
10. Describe cutting and abrasive processes from a system-oriented point of view.
11. Which are the input variables of cutting and abrasive processes?

12. Which effect variables can be relevant? Which criteria are used for evaluating cutting and abrasive processes?
13. Which are the relevant process parameters in cutting and abrasive processes?
14. What are the technological parameters (i.e., largely predetermined manipulated variables) in drilling processes?
15. Compare the essential input variables in turning processes with those in drilling, broaching and milling.
16. How do we determine the mean chip thickness in peripheral face milling and in down milling?

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