1. Turning

Turning is used for production of all size components which are symmetrical about their axis of rotation [14]. Turning means that part is rotating while being machined. The starting material is usually a workpiece that has been made by other processes, such as casting, shaping, forging, extrusion, and drawing [7]. Turning is one of the oldest cutting processes known.

1.1. Kinematics

Kinematics of turning (fig. 1.2.):
- primary motion – rotary motion of workpiece,
- feed motion – linear motion of tool.

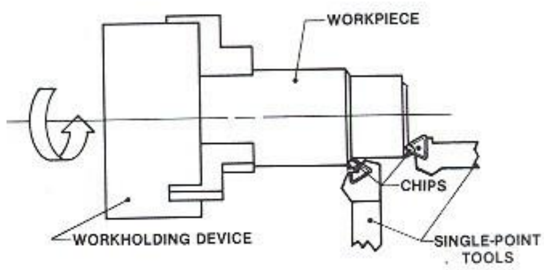


Fig. 1.2. Schematic illustration of turning operation.

1.2. Basic turning operations

Turning processes are versatile and capable of producing a wide variety of shapes:
- Straight turning (fig. 1.3.), conical (fig. 1.4.), curved and grooved workpieces, such as shafts, spindles, pins, handles, and various machine components

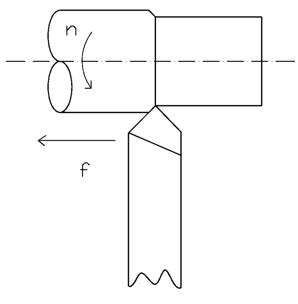
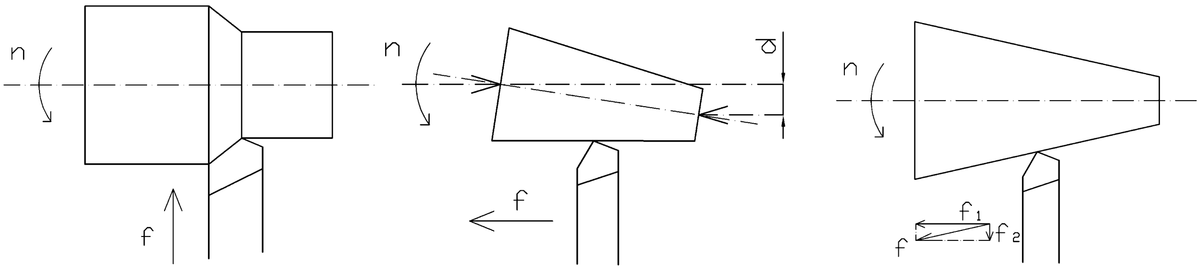
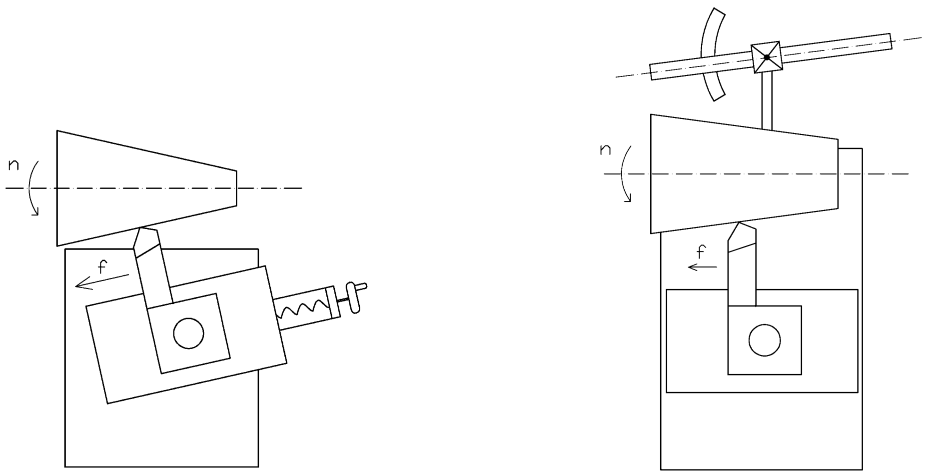


Fig. 1.3. Straight turning[1]

[1] Most of schematic illustrations are made by Piotr Sokołowski



a) form cutter b) shifting tailstock c) complex feed



d) upturned turn-table (compound rest) e) using straight-edge

Fig. 1.4. Methods of taper turning (conical turning)

- Facing, to produce a flat surface at the end of the part (fig. 1.5).

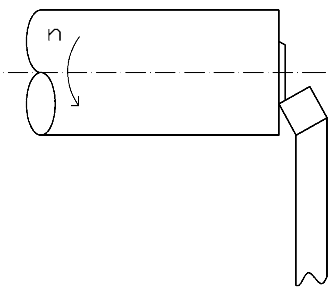


Fig. 1.5. Facing

- Producing various shapes by form tools, such as for functional purposes or for appearance (fig. 1.6.).

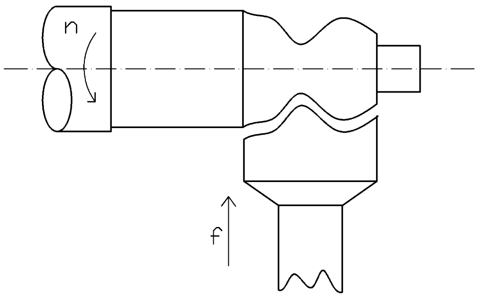


Fig. 1.6. Form turning with form cuter

- Boring, to enlarge a hole made by a previous process, or in a tabular workpiece or to produce internal grooves (fig 1.7.).

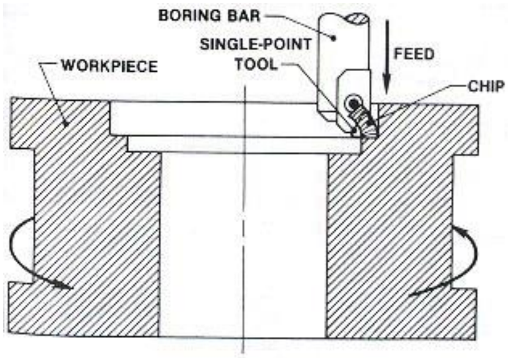


Fig. 1.7. Vertical boring [15]

- Drilling, to produce a hole, which may be followed by boring to improve its accuracy and surface finish (fig 1.8.).

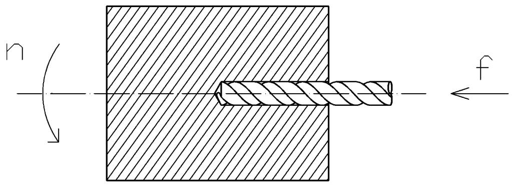


Fig. 1.8. Drilling

- Parting, also called cutting off, to cut a piece from the end of a part, as in making slugs or blanks for additional processing into discrete products (fig 1.9.).

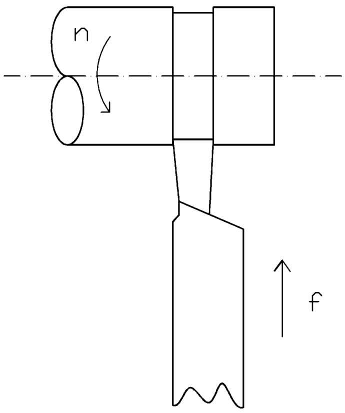


Fig. 1.9. Cutting off

- Threading, to produce external and internal threads in workpieces (fig 1.10.).

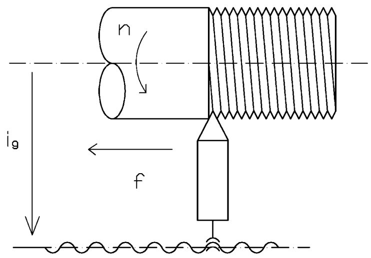


Fig. 1.10. Thread cutting

- Knurling, to produce regularly shaped roughness on cylindrical surfaces, as in making knobs (fig 1.11.).

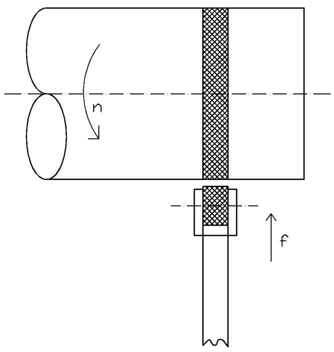


Fig. 1.11. Knurling

1.3. Basic formulas

- Feed per revolution (*f*)

$$f = \frac{v_f}{n} \qquad \left[\frac{\text{mm}}{\text{rev}}\right]$$

v_f – feed speed [mm/min],
f – feed per revolution [mm/rev],
n – rotational speed of the workpiece [rev/min]

- Machine time (t_m)

$$t_m = \frac{L}{v_f} = \frac{l_i + l_c + l_o}{f\,n} \qquad [\text{min}]$$

L – action path [mm],
l_i – tool input,
l_c – cutting length (feed path),
l_o – tool output,

- Cutting time (t_c)

$$t_c = \frac{l_c}{v_f} \qquad [\text{min}]$$

- Cutting speed (v_c)

$$v_c = \frac{\pi\, d\, n}{1000} \qquad \left[\frac{\text{m}}{\text{min}}\right]$$

d – diameter of the workpiece [mm],
n – rotational speed of the workpiece [rev/min]

- Material removal rate (*MRR)* – volume of material removed per unit time

$$MRR = 1000 v_c\, a_p\, f \qquad \left[\frac{\text{mm}^3}{\text{min}}\right]$$

a_p – depth of cut [mm],
f – feed per revolution [mm/rev],

1.4. Machine tools (lathes) [14]

1.4.1. Centre lathes – universal (screw-cutting) lathe, manufacturing lathe

Centre lathe (fig 1.12.) allows to perform typical turning operations, such as external and internal turning, boring and taper turning. The feed shaft is a part of all-kinds centre lathes. It is a shaft with a key-way along its whole length, drives the saddle. The universal lathe has an extra lead screw, which has a high-precision thread. It provides the feed motion for screw cutting.
Long components are normally mounted between two *centres*. When component is slender in relation to its length, it will be supported with an additional *steady* (*following rest*, *back rest*) to prevent flexure. Short components are held on one side only in a *chuck* or, when the component's shape is non-symmetrical in relation to the axis of rotation, on a *face plate*.
Heavy-duty lathes may be used to machine work up to 20 m long and 6 m diameter. They are used for the turning of rolls for rolling mills, marine drive shafts, turbine rotors etc. Compared with smaller machines of this form of construction, the special features of the heavy-duty lathes are the separate guides for the saddle and tailstock. In order to increase output, some lathes are fitted with two saddles [14].

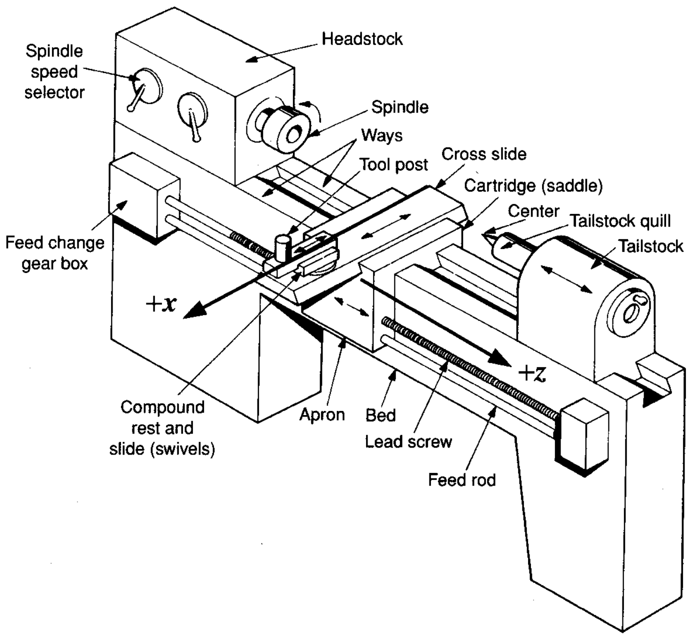


Fig. 1.12. Universal lathe fitted with feed shaft and lead screw [8].

1.4.2. Vertical lathes (boring mill)

Vertical lathes, known also as vertical boring machines, are mainly used for the machining of heavy workpieces (fig 1.13.). They offer the advantage of easier support of heavy workpiece, as well as simpler clamping arrangements for it.
By paying special attention to make provisions which will enable heavy workpieces to be completely machined in one set-up, idle machine times are minimized [14].

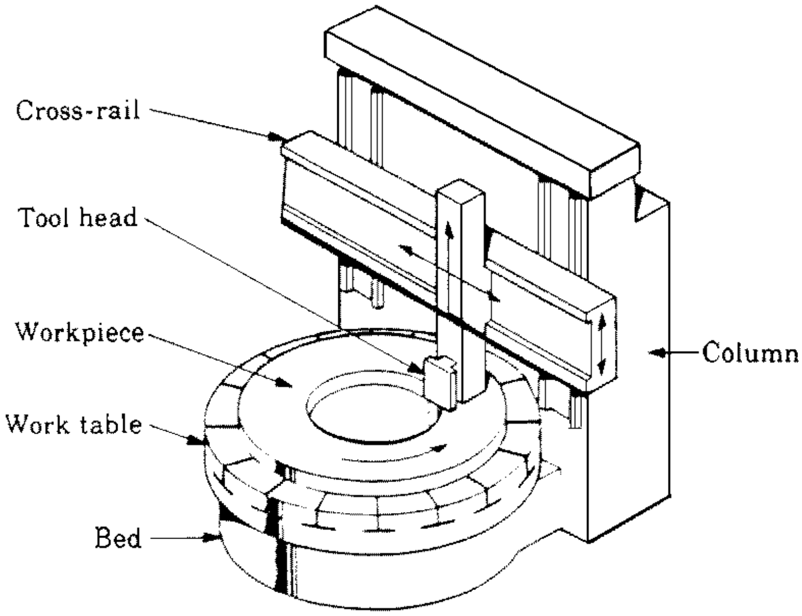


Fig. 1.13. Schematic illustration of the components of a vertical boring mill [7].

1.4.3. Numerically controlled (NC) lathe

As a result of the demands for small-batch production of turned components, numerically controlled automatic lathes with high output rates are being increasingly used today for the manufacture of small- and medium-sized workpiece (fig 1.14.). These machines are distinguished by their ability to change automatically cutting speed, feed rates, direction of feed and cutting tools. The loading and unloading of the workpiece may also be automated by the use of handling devices.

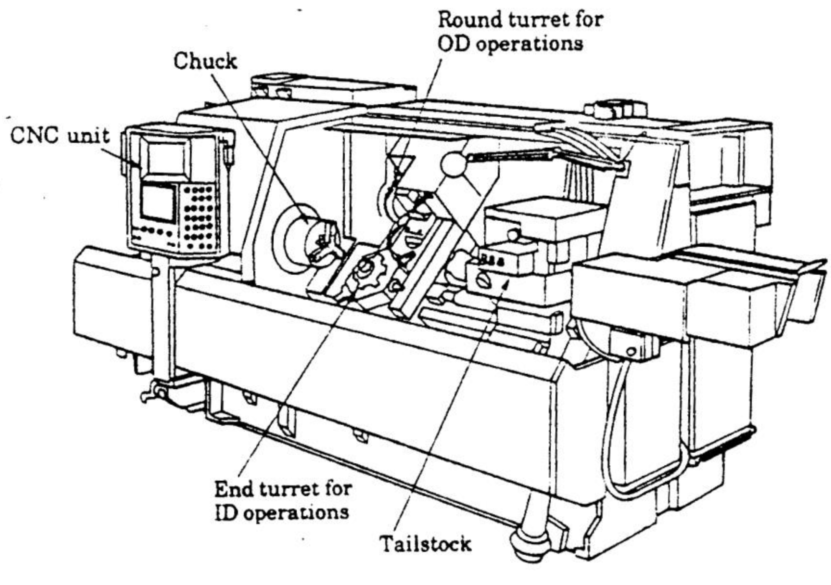


Fig. 1.14. Main components of the CNC lathe [7].

Figure 1.15. shows a numerically controlled automatic lathe for chuck work and centre work, with a drum-turret head for tool mounting. When the order of mounting tools is arranged in conjunction with the operation lay-out for the work, care must be exercised to avoid collisions between the workpiece and the tools [14].

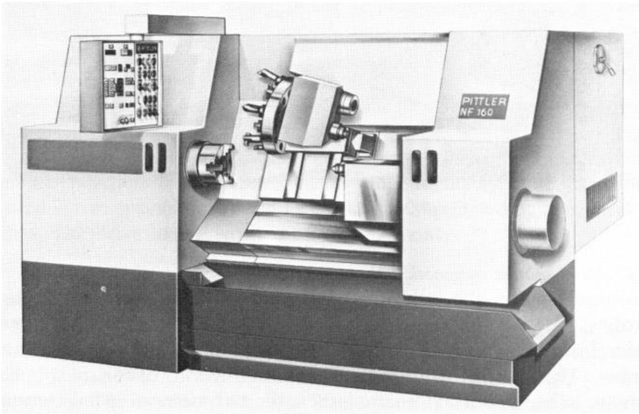


Fig. 1.15. A computer numerical control (CNC) lathe [14].

With a star-turret heads, there is only a small danger of collision, as the tools are spaced further apart. Figure 1.16. shows a star-turret head is interchangeable, permitting pre-setting of the tools away from the machine, in order to reduce the nonproductive setting times.
The solutions of other revolving tool turrets are presented in figs 1.17, 1.18 and 1.19.

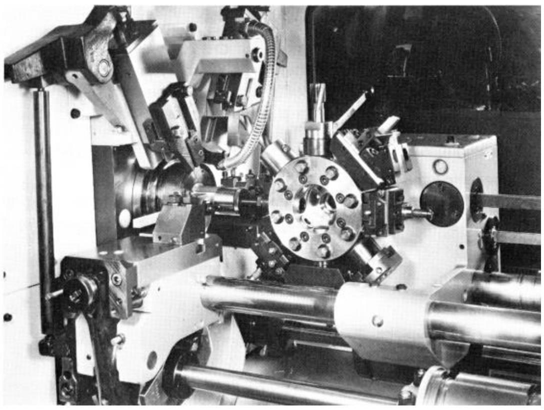


Fig. 1.16. Star-turret head (Traub) [14].

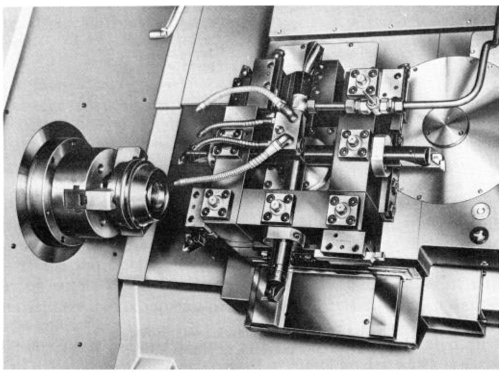


Fig. 1.17. Four-faced revolving turret with eight tool positions (Pittler) [14].

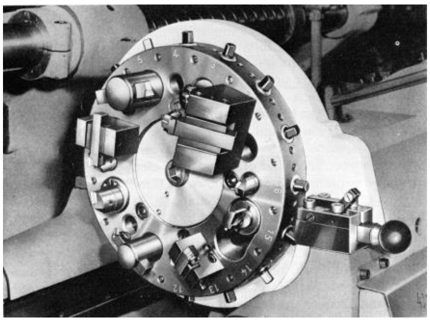


Fig. 1.18. Vertical disc revolving turret for automatic lathes (Pittler) [14].

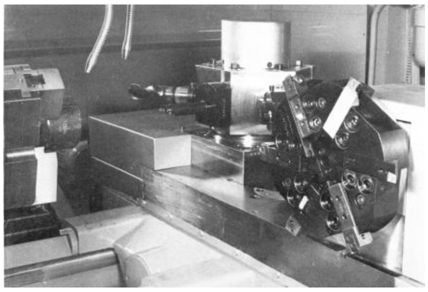


Fig. 1.19. Cross slide with horizontal and vertical tool turret on a NC lathe (Gildemaister) [14].

1.4.4. Multi-spindle automatic lathe

Multi-spindle automatic lathes machine the workpiece at several work-station. According to the number of spindles, four, six, or eight components are machined simultaneously. Figure 1.20. illustrates the construction of a six-spindle bar automatic lathe. In bar automatic lathes, the bar material is fed through the spindle (the parting-off operation – the last operation in the cycle – separates the component from the bar). On chucking automatic lathes, the components are placed into, and removed from the chuck, either automatically from a magazine or by hand. The feed motions are controlled predominantly by the use of disc cams.

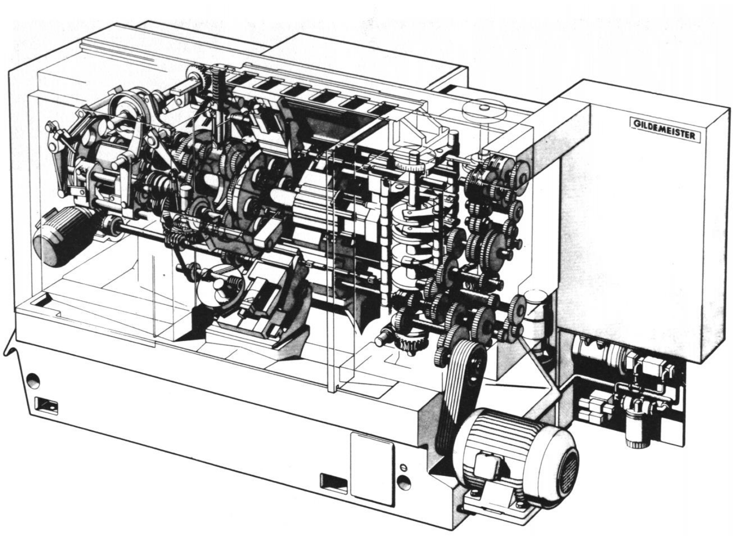


Fig. 1.20. Multi-spindle automatic lathes [14]

1.5. Turning tools (lathe tools)

1.5.1. Construction

Conventional solid turning tools have a simple form of rectangular prism with a formed blade (cutting edge) (fig. 1.21.). The modern solutions are based on complex tool with a tip clamped to the adapter socket (fig. 1.22.).

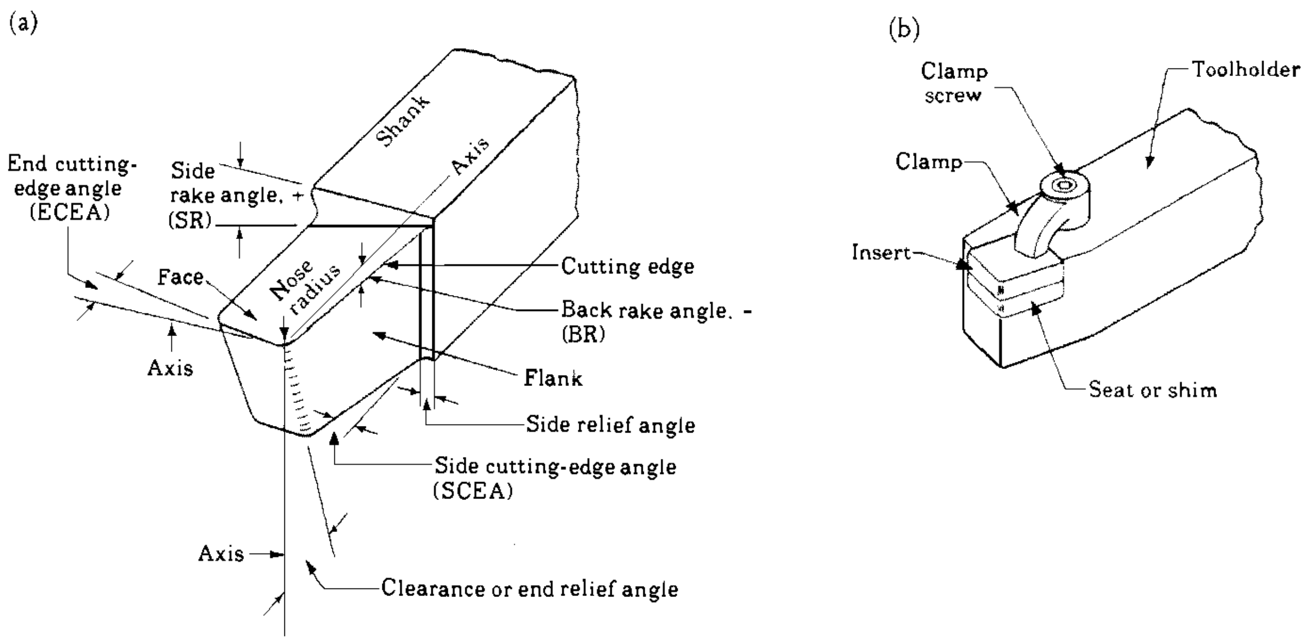


Fig. 1.21. Turning cutter: a) schematic illustration of a right-hand cutting tool. b) Although these tools have traditionally been produced from solid tool-steel bars, they have been largely replaced by carbide or other inserts of various shapes and sizes [7].

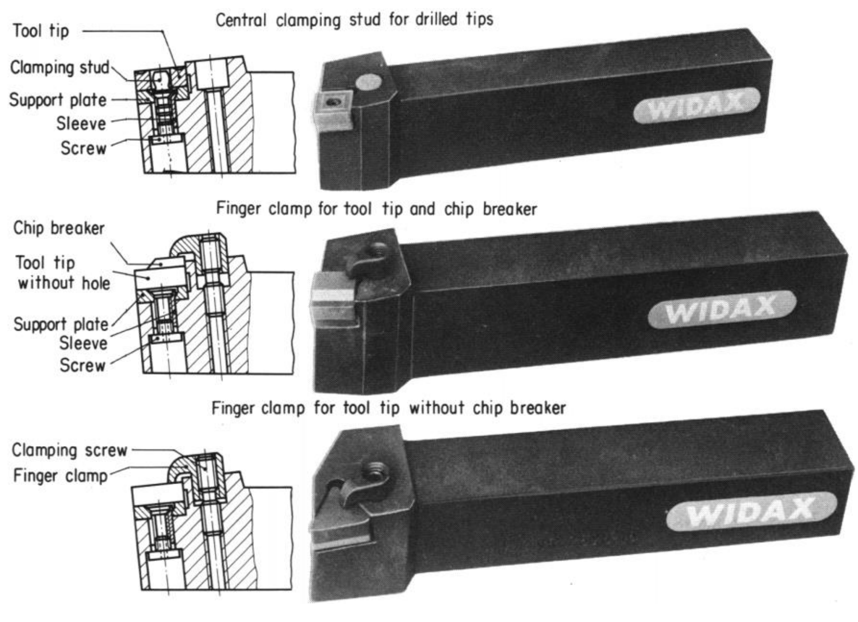


Fig. 1.22. Various clamping systems for interchangeable ('throwaway') tool tips (Widia-Krupp) [14].

An example of typical tooling is shown in fig. 1.23., in which various insert geometries and tool-holder shapes are shown.

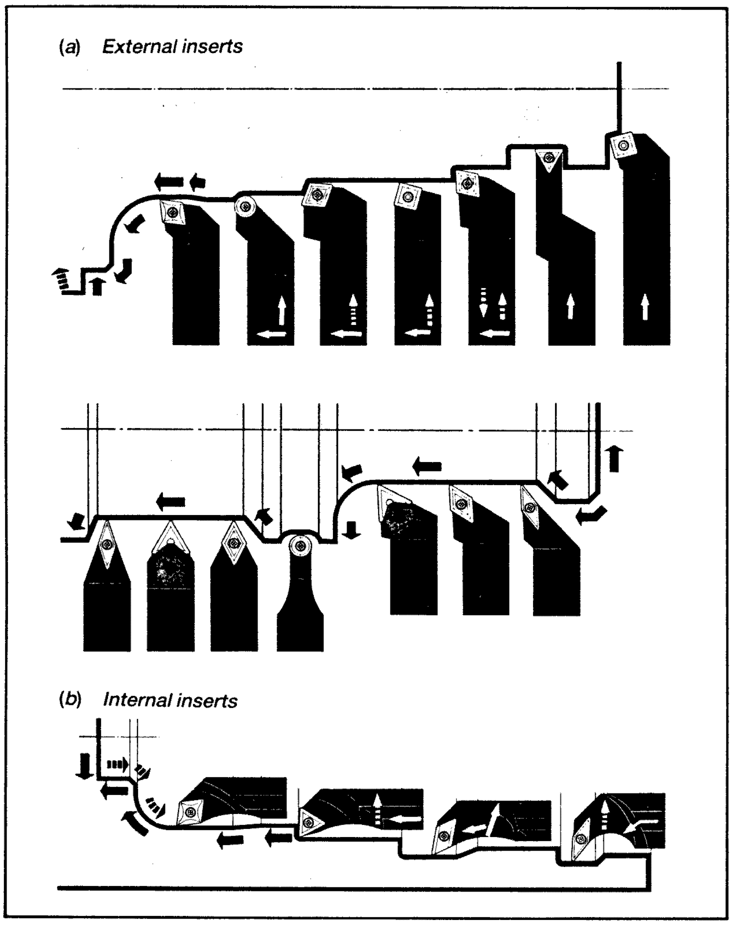


Fig. 1.23. Using typical turning insert geometries to machine different features on a workpiece [11].

1.5.2. Surfaces on the workpiece

Work surface is the surface to be machine and machined surface is the surface after machining (fig 1.24.).

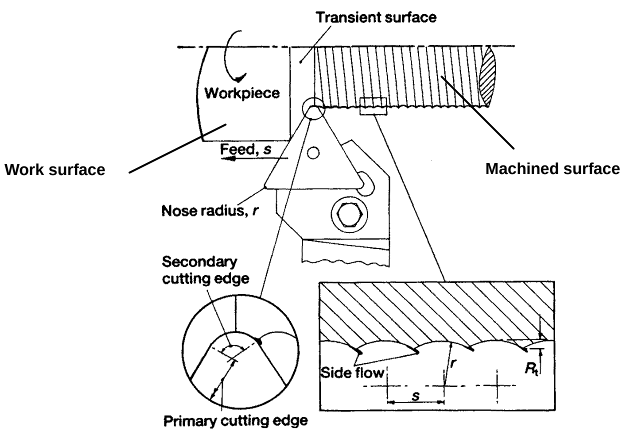
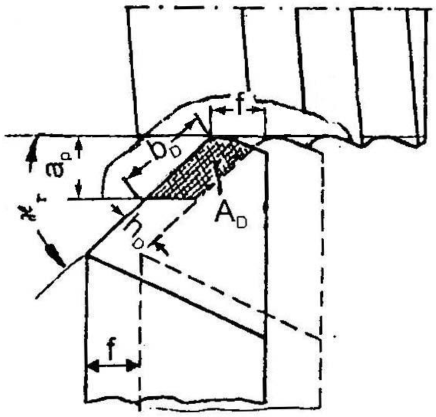


Fig. 1.24. Surfaces on the workpiece

1.5.3. Unformed cut dimensions (section of the cut)

Section of the cut is defined by technological parameters (feed, depth of cut) and geometrical ones (width of cut, thickness of cut) (fig. 1.25.).



f – feed ,
a_p – depth of cut,
b_D – width of cut,
h_D – thickness of cut,

$$b_D = \frac{a_p}{\sin\kappa_r} \qquad h_D = f \sin\kappa_r$$

A_D – nominal cross section area of cut,

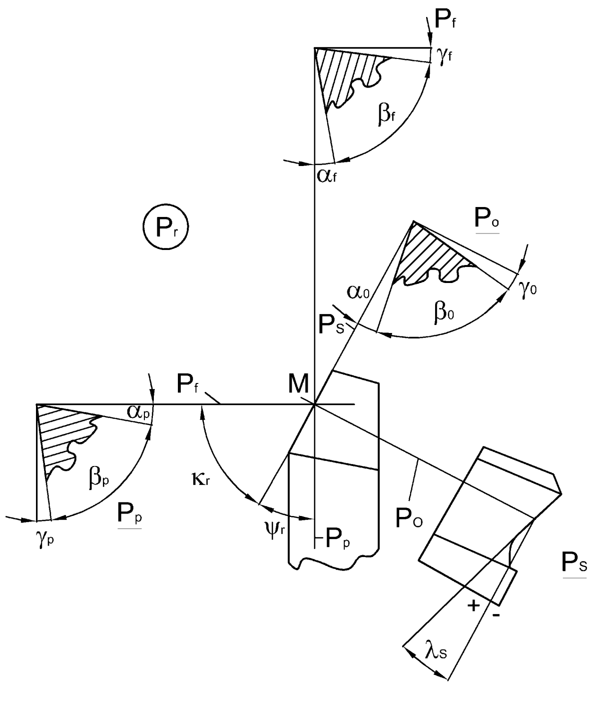
$$A_D = a_p\ f = b_D\ h_D$$

Fig. 1.25. Parameters of the section of the cut

1.5.4. Geometry of the tool

The shape of the blade is define by *tool contour and angles* (*geometry of the tool)* in three reference systems:

- “tool-in-hand” system (fig 1.26.),



Tool system planes:
M – selected point on the cutting edge,
P_r – tool reference plane,
P_s – tool major cutting edge plane,
(P_s‘ – tool minor cutting edge plane)
P_o – tool orthogonal plane,
P_f – assumed working plane,
P_p – tool back plane,

Tool angles:
α_o – tool orthogonal clearance,
γ_o – tool orthogonal rake angle,
β_o – tool orthogonal wedge angle,
κ_r – tool entering (cutting edge) angle,
ψ_r – tool approach angle (UK), tool lead angle (USA),
λ_s – tool cutting edge inclination.

Fig. 1.26. Geometry of the turning cutter in “tool-in-hand” system

- "tool-in-use" system (tool kinetic system) (fig 1.27.),

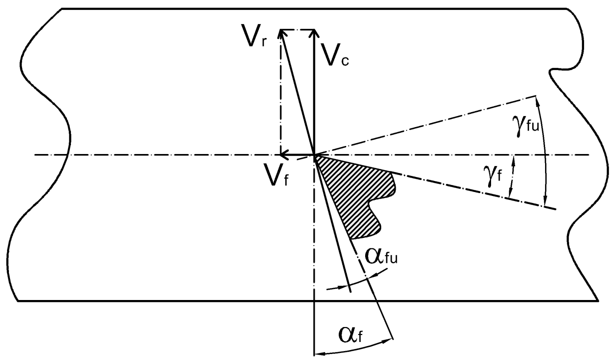
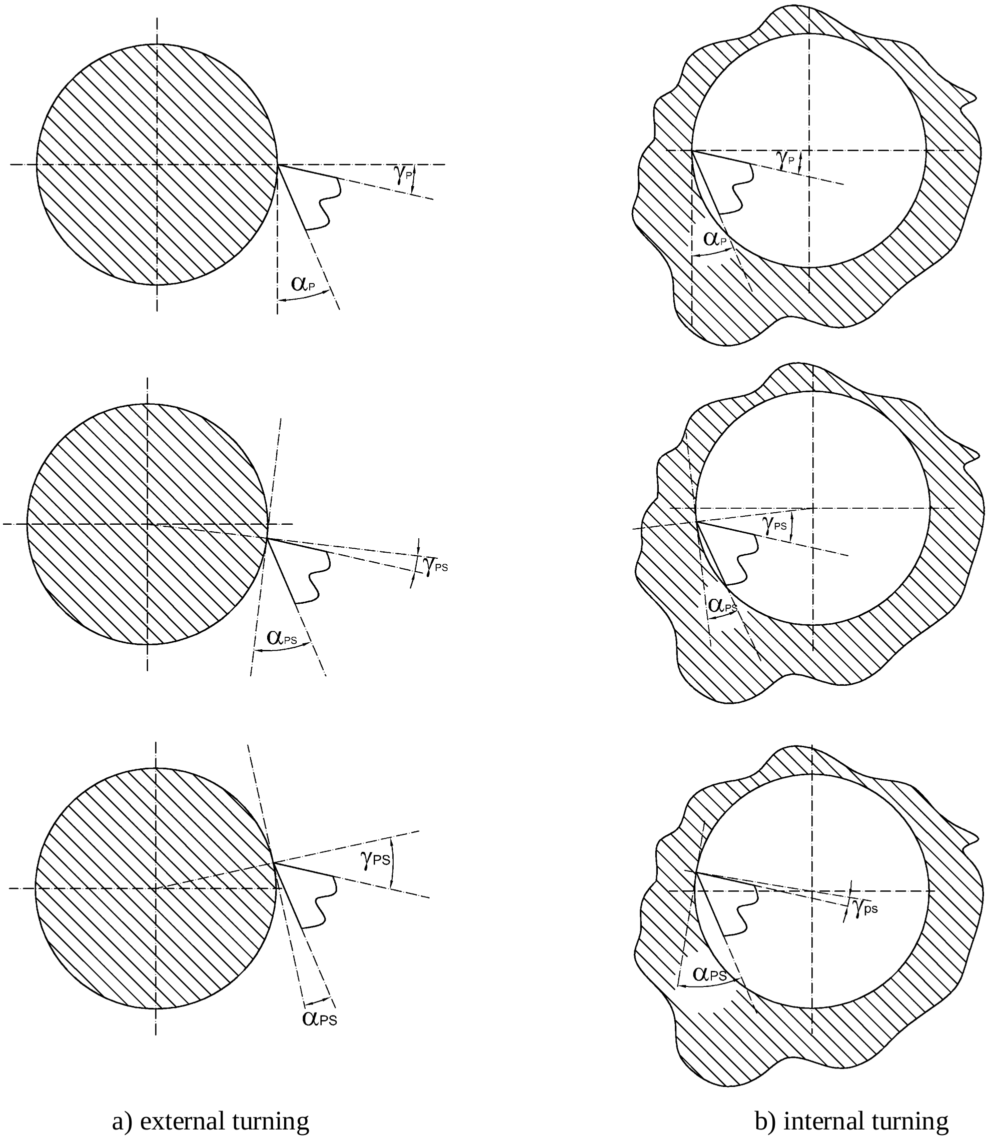


Fig. 1.27. Geometry of the turning cutter in "tool-in-use" system (kinetic system)

- tool setting system (fig 1.28.).



a) external turning b) internal turning

Fig. 1.28. Angles of the turning tool in setting system