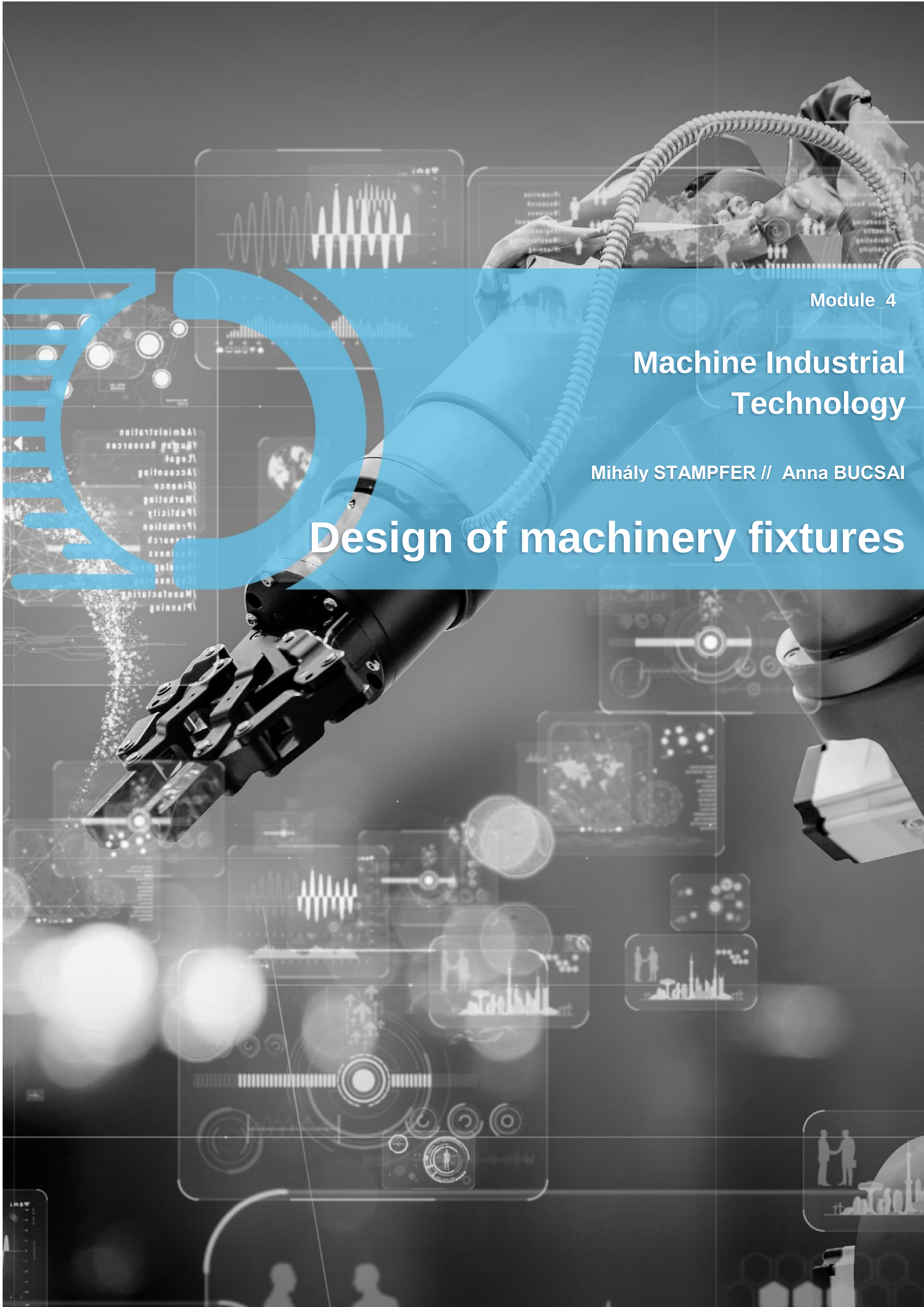

Module_4

Machine Industrial Technology

Mihály STAMPFER // Anna BUCSAI

Design of machinery fixtures

Module_4

Industrial Technology

Mihály STAMPFER // Anna BUCSAI

Design of Machinery Fixtures

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1. THE ROLE OF MACHINERY FIXTURES

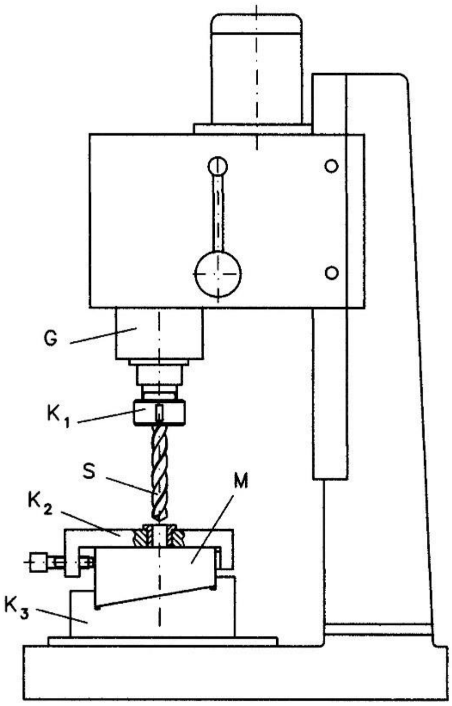
The components are machined in a machining system consisting of the workpiece, the fixture, the machine tool and the tool (Figure 1-1.). Fixtures are defined as equipment which, in addition to the machine tool and the tool, is required during the mechanical machining, are needed in carrying out the operations but that are not directly involved in the shaping of the workpiece.

DEPENDING ON THEIR ROLE, FIXTURES CAN BE:

_tool holders
_drill jigs
_workpiece holder fixtures

The TOOL HOLDERS (K1) establish a link between the main spindle, the tool holder and the tool shank of the machine tool. The tool shanks and connecting parts as well as the spindle ends and tool holders are standardized and therefore the tool holders can be purchased commercially or from specialised companies. During the planning, the task usually comes down to selecting the right fixture.

DRILL JIGS (K2) are used on conventional drilling machines but often the tool guide is part of the workpiece holder fixture. Modern NC controlled machines do not require tool guide because the exact location of the bores is ensured by the control and the movement system of the machine tool.

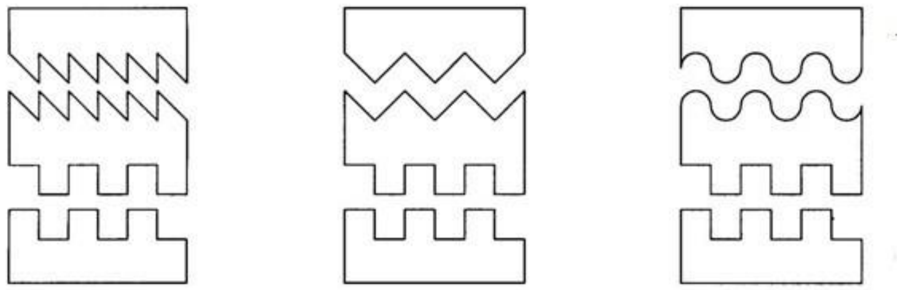


1-1. Figure The symbolic representation of the role of the fixture

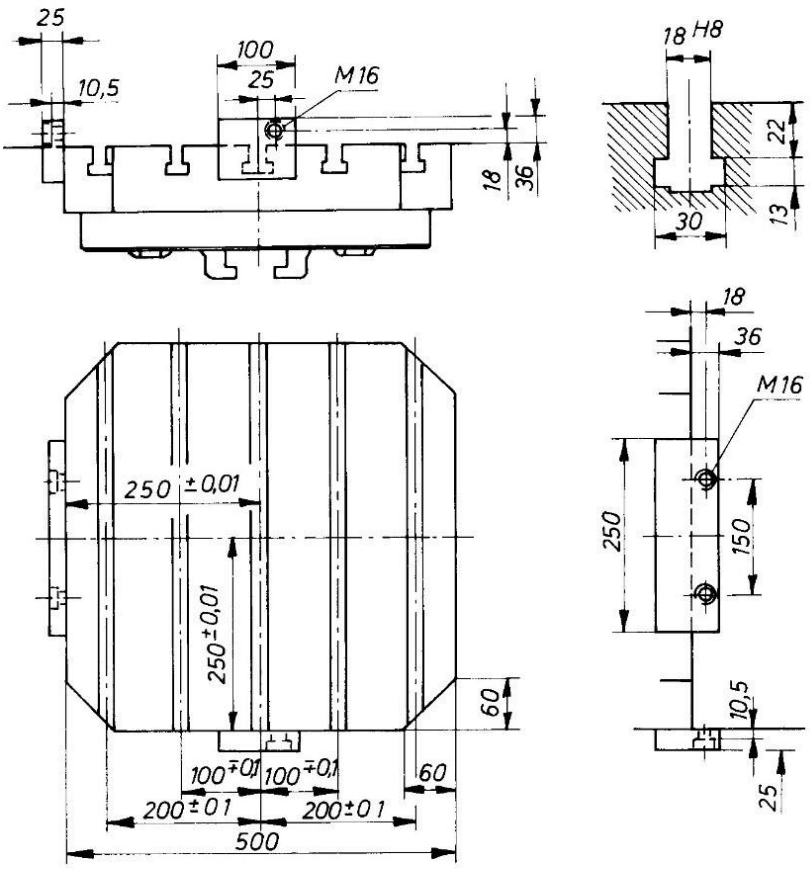
THE WORKPIECE HOLDER fixtures or, in short, holder fixtures (K3) create a connection between the workpiece and the machine tool (machine table or the main spindle on lathe machines). The variety of workpieces is basically limitless. This wide variety of workpieces should be ’fitted’ to a machine table of a given design. It is clear that it cannot be achieved by direct connection, so a ’mechanical interface’ should be placed between the machine table and the workpiece. This role is carried out by the holder fixture. The symbolic representation of this role is shown in Figure 1-2. As an example the machine table design and measurements of the machining centre ’MAKINO MC65’ are shown in Figure 1-3.

Due to the variety of workpieces, in most cases, the holder fixture should be designed separately for each workpiece and for each operation of the manufacturing process. The knowledge required to solve this task is presented and discussed below.

The basic function of a holder fixture is to locate and clamp the workpiece (sometimes also to guide the tool).



1-3. Figure The symbolic representation of the role of the fixture



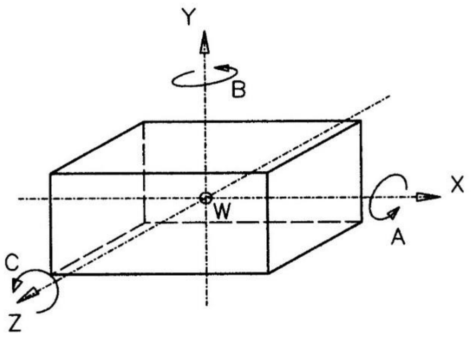
1-2. Figure The machine table of the machining centre „MAKINO MC65”

2. WORKPIECE LOCATING AND LOCATING DEVICES

Good locating planning is a key part of determining the clamping and the design of the device.

2.1 LOCATING OF THE WORKPIECE

2.1.1 GENERAL PRINCIPLE OF LOCATING



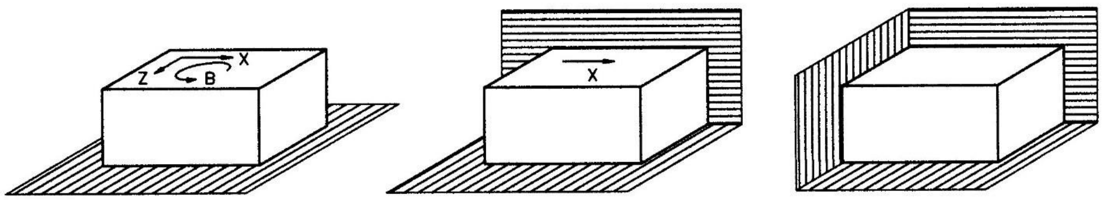
2-1. Figure The six movement-freedom of a solid body

If we consider the workpiece as a free, solid body, we can bring it into any location in space defined by a rectangular coordinate system with six different displacements (Figure 2-1.), or we can say that the workpiece has six degrees of freedom of motion:

_three translations along the coordinate axes (X, Y, Z)

_three rotations around the coordinate axes (A, B, C)

It is easy to see that a workpiece will be in a precisely defined locaion if these six movement-degrees of freedom are bound (taken away). If the size and shape of the workpieces were absolutely precise, the location of the workpiece could be defined by three perpendicular planes (Figure 2-2.).



2-2. Figure_Bounding the degrees of freedom of motion of a free body

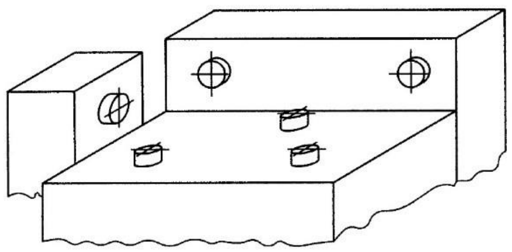
a) three degrees of freedom of movement

b) one degree of freedom of movement

c) no degrees of freedom of movement

Placing the piece on a plane parallel to the Z-X plane, its three degrees of freedom are bound and its location along the Y axis and rotations A, C are defined. A further two degrees of freedom can be bound with a plane parallel to the X-Y plane, these are the translation along the Z axis and the rotations along the B axis. Finally, a third plane perpendicular to the previous two planes is used to define the remaining single degree of freedom.

The surfaces of the workpiece that are used for locating are called the CLAMPING BASE SURFACES.



2-3. Figure_The 3-2-1 principle

Since in reality it is only possible to produce workpieces with a certain dimensional spread and shape error, locating with planes would introduce a whole range of uncertainties. Therefore, in practice, the so-called SIX-POINT LAW, also known as the 3-2-1 PRINCIPLE, is used, according to which the location of a workpiece can be determined by supporting it with six fixed points (Figure 2-3.):

_3 degrees of freedom of the workpiece are bounded by a 3-point support lying in a plane. This is called a three-point or plane locating base.

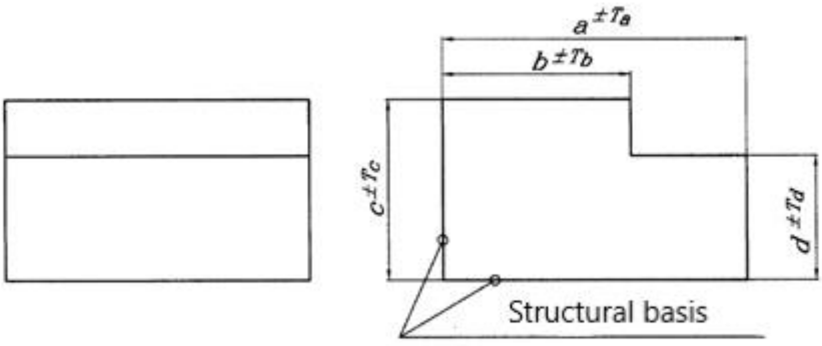
_in a plane perpendicular to the plane locating plane, with a 2-point support, 2 more degrees of freedom of the workpiece are bound. This is called a two-point, or guiding base. (In the literature it is also called a supporting base.)

_in the plane perpendicular to the plane locating and supporting planes, we also tie down the remaining 1 degree of freedom of the piece with 1 point of support. This is called a single point or endwise locating.

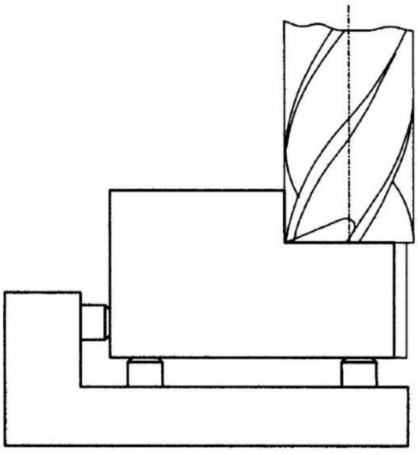
Together, the guidance and the endwise locating are called side locating.

2.1.2 BASE SURFACES

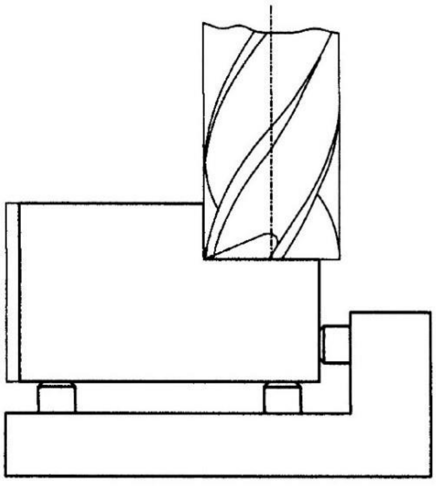
Each component has to serve a specific function (task) within a machine or structure. The sizing of the component should be specified in the component drawing in such a way that it can subsequently perform the intended function. The sizes are given and toleranced in relation to a certain surface. Such surfaces are called STRUCTURAL BASES (Figure 2-4.). In all cases of fixture design, the structural bases must first be identified. If possible, the structural bases should also be selected as the clamping base surfaces because, due to the size dispersion of the workpieces, only these surfaces will always be in the same location relative to the holder fixture. Figure 2-5. illustrates, for the example shown in Figure 2-4., the milling of a stepped surface when the clamping base is the same as the structural base. If, for some reason, the structural base cannot be used as the clamping base, we are forced to use a surface other than the structural base as the clamping base, but in this case we have to account for the base change error (Figure 2-6.). If we do not choose the structural base as the capture base, then in the example shown in Figure 2-4., size b can only be feasible if the tolerance (T_a) of size a is smaller (more strict) than the tolerance (T_b) of size b. The magnitude of the base change error is the same as the size dispersion due to the previous machining.



2-4. Figure_Structural bases of the component



2-5. Figure_ The clamping base correspond to the structural base (thin line indicates the dimensional dispersion from the previous machining)



2-6. Figure_ The clamping base does not correspond to the structural base (thin line indicates dimensional dispersion from previous machining

2.1.3 TOTAL AND PARTIAL LOCATING

In some cases, it is not necessary to have a precise locating in all directions. In such cases, only the displacement possibilities that are important for machining accuracy need to be bound. Three cases can be distinguish:

_unidirectional locating (Figure 2-7, (a)), where the workpiece only needs to be laid up (e.g. surface grinding on a magnet table)

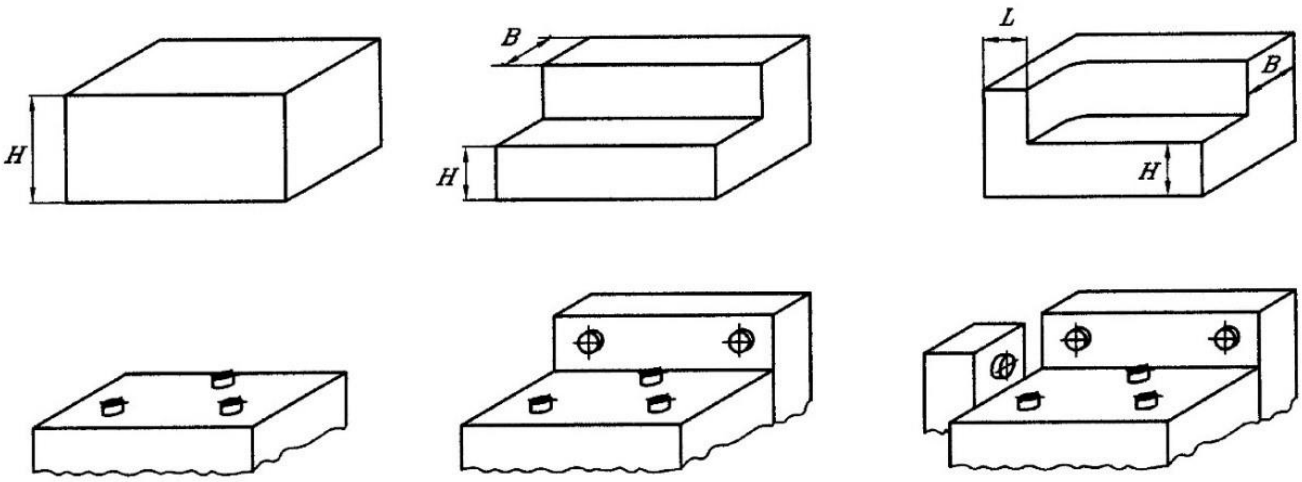
_bidirectional locating (Figure 2-7(b)), where the workpiece must be supported and laid up (e.g. milling a stepped surface along the entire length of the workpiece).

_tridirectional, or total locating (Figure 2-7(c)), where the workpiece must be laid up, supported and endwise locating)

a)

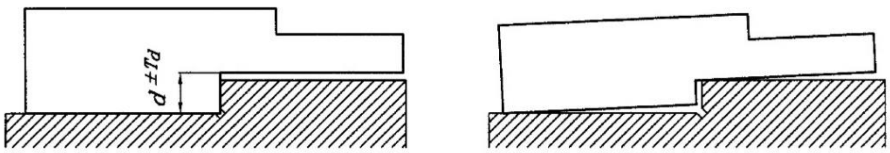
b)

c)

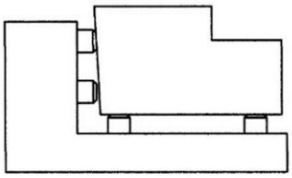


2-4. Figure_Total and partial locating

OVER-LOCATING An over-locating occurs when you want to support the piece at more than the support points defined in the 3-2-1 principle. It is a mistake if more than one plane locating plane is used (Figure 2-8), if the guiding is performed at more than two points (Figure 2-9), or if the endwise locating is carried out at more than one point.



2-5. Figure_ Over-locating on the plane locating surface



2-6. Figure_ Over-locating on the guiding surface

The problem of over-locating arises from the size spread of the previous machining. The more accurate the workpiece (surface) the less dangerous. If the plane locating base is an accurately machined surface, then the entire surface can be used for plane locating (e.g. grinding on a magnet table) instead of three-point support.

2.1.4 LOCATING WITH CYLINDRICAL SURFACES

It is often the case that a sub-task of locating is not (or cannot be) performed with a flat surface, but with a cylindrical outer surface or a bore.

2.1.4.1 USE OF SHORT CYLINDRICAL SURFACE

When the plane locating (three-point base) is already defined, the workpiece still has three freedoms of movement, two translations and one rotation. Of these two translations, one can be bound by a short section of cylindrical surface. For an external surface, two tangential planes perpendicular to the plane locating surface and to each other or so-called short prisms can be used (Figure 2-10.).

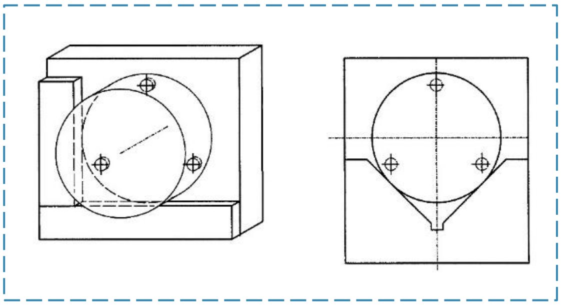


Figure 2-10. Partial locating of a short rotating body part

a) with tangential planes

b) with short prism

For an internal cylindrical surface (bore), a short pin is used (Figure 2-11.). The short prism and the short pin should theoretically be considered as zero length, otherwise such a locating would lead to over-positioning.

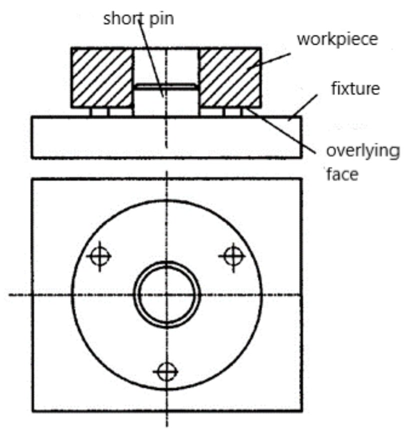


Figure 2-11. Use of internal cylindrical surface and short pin

" Short pin " centring can also be thought of as having the outer cylindrical surface on the workpiece and the bore in the fixture (Figure 2-12.). This is less common and is occasionally used on lathes.

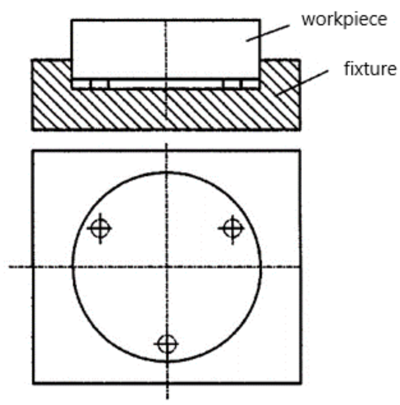
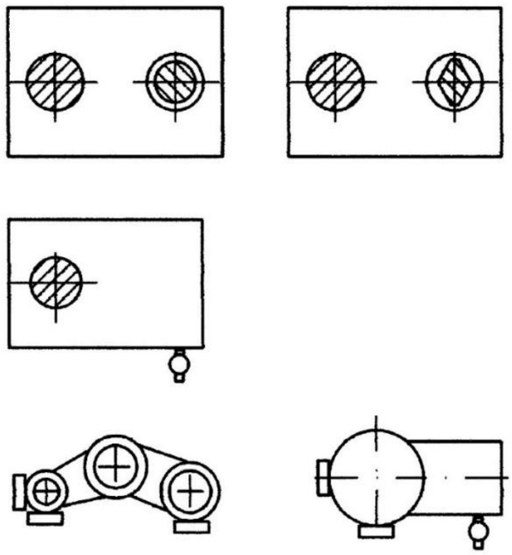


Figure 2-12. Use of external cylindrical surface and short bore

For rotating body-type workpieces, it is often not necessary to tie off the rotation around the axis of rotation of the workpiece. If it is necessary, then the endwise locating has to be resolved, for which some non-rotating surface can be used.

For cabinet-like and prismatic pieces, the blocking of the remaining one rotational movement is called orientation. This can be done with another bore, a flat surface or an external cylindrical surface (Figure 2-13.).



Side locating using two bores

Side locating with one bore and one flat surface

Side locating with external cylindrical surfaces

Figure 2-13. Side locating options for cabinet-like or prismatic pieces [18]

In two-bore (two-pin) side locating, to avoid over-definition only one pin fits the corresponding bore and ties off two degrees of freedom (centring pin), while the other is either flattened or significantly smaller in diameter than the bore and ties off only the remaining rotation possibility (orientation pin).

2.1.4.2 USE OF LONG CYLINDRICAL SURFACE

Long cylindrical pieces are located using a long prism or two tangential planes. As the tangential plane is theoretically in contact with the piece along its entire or significant length along its formation, this is considered to be two-point support. The two planes bound the four degrees of freedom of the piece: two translations and two rotations. This leaves the piece with two degrees of freedom: one translation along the rotational axis and one rotation around the rotational axis. The remaining translations along the rotational axis of the piece can be bound by supporting the front surface of the piece at a point (Figure 2-14.).

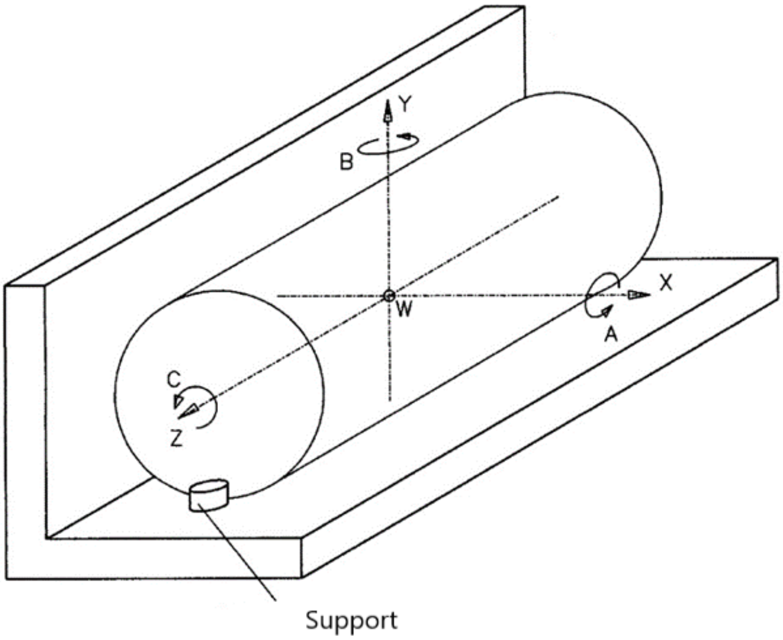


Figure 2-14. Rotating body in long prism

If rotation around the longitudinal axis of the piece needs to be bound, then a non-rotating surface such as a cross hole, groove or flattening should be used. An example is shown in Figure 2-15. Here, the SIX-POINT LAW is applied, following the 4-1-1 PRINCIPLE.

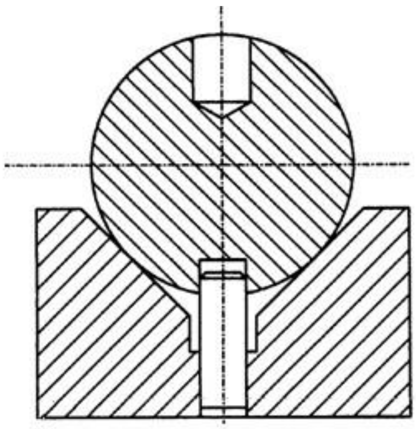


Figure 2-15. Bonding the rotation of a workpiece around its longitudinal axis in a prism

2.1.5 CENTRING

Centring is the case of locating where the structural base is not a real surface, but one or more imaginary midplanes. Here the aim is to ensure that the centre plane (plane of symmetry) is in the same location relative to the tool. It should be noted that here again the clamping base can only be a real surface, usually a cylindrical or spherical surface in contact with the corresponding elements of the fixture.

CENTRING-ACCORDING TO THE NUMBER OF DEFINED CENTRE PLANES CAN BE:

_unidirectional, where a centre plane is provided in the same locaion,
_bidirectional, where two centre planes (centre axis) are provided, and
_tridirectional, where three centre planes (centres) are provided in the same location.

UNIDIRECTIONAL CENTRING can be performed with a fixed prism (Figure 2-15., Figure 2-10(b)).

BIDIRECTIONAL CENTRING can be performed on the outer surface of the workpiece with two moving prisms. The centring movement is most often achieved by a threaded spindle with a right-hand thread on one side and a left-hand thread on the other side (Figure 2-16.).

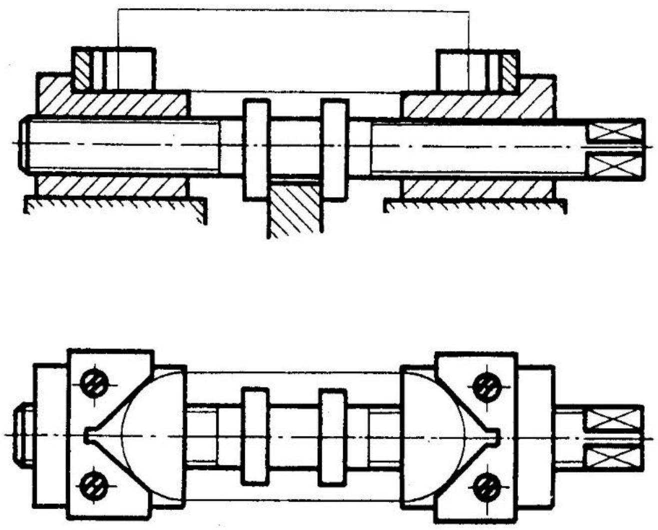


Figure 2-16. Bidirectional centring with moving prisms.

BIDIRECTIONAL CENTRING WITH MANDRELS

We use mandrels when the centring has to be solved on an internal cylindrical surface. Depending on their design, mandrels can be made with a cylindrical or conical centring surface.

Cylindrical mandrels can be further subdivided into short and long mandrels. Short mandrel centring has the same locating function as short mandrel centring (Figure 2-11.). It is most often used in the main spindle of a lathe or in the object spindle of a grinding machine and is also known as the swing mandrel.

The cylindrical part of the long mandrel bounds the four degrees of freedom of the workpiece (similar to the long prism), and the perpendicular surface bounds only one (Figure 2-17.). The long mandrel is clamped between the tips together with the workpiece. The torque transmission can be achieved by means of a nut clamp, a tight fit or a latch. The diameter of the mandrel is most often made with a tolerance of g5 or j6, which can sometimes be increased to IT 4.

It should be noted that cylindrical mandrels do not provide a precise centring, because in order to fit all workpieces, the mandrel diameter must be matched to the lower limit of the bore size and some tolerance is also required to allow for smooth fitting of the workpieces. The expected eccentricity is equal to half the large tolerance.

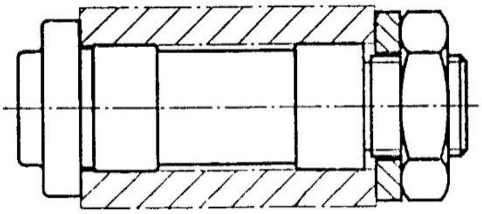


Figure 2-17. Bidirectional centring with long spike [12]

The tapered mandrel is made with a slight taper (1:k = 1:500 ....1: 2000), so it centres a point on the workpiece axis precisely, but guides with an error corresponding to the taper (Figure 2-18).

The axial location of the workpiece varies with the size of the bore.

THEREFORE THE MANDREL MUST BE MADE LONGER THAN THE LENGTH OF THE WORKPIECE:

$$L = l + k \cdot T_{bore}$$

WHERE: $\frac{1}{k}$ the taper

l the length of the workpiece

T_{bore} the tolerance of the bore

THE BIGGER DIAMETER OF THE TAPERED MANDREL:

$$d_2 = d_{min} + T_{furat}$$

WHERE: d_{min} the minimum size of the bore

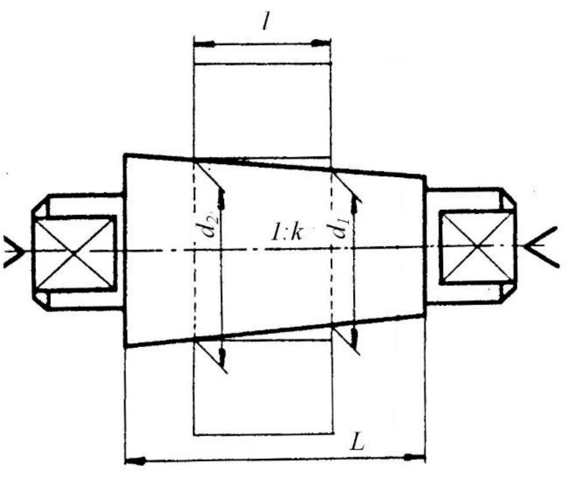


Figure 2-18. Bidirectional centring with tapered mandrel

Precise centring on internal cylindrical surfaces can only be achieved with an expansion mandrel. Their construction is more complex and the realistic precision that can be achieved depends on the precision of the mandrel elements.

THE EXPANSION MANDREL CAN ALSO BE USED FOR CLAMPING (FIGURE 2-19.):

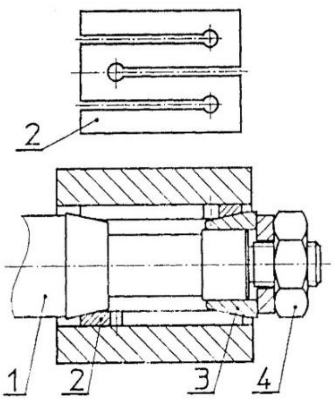


Figure 2-19. Expansion mandrel [12]

In addition to the solutions listed above, there are of course special solutions which are mainly used for large components, an example of which is shown in Figure 2-20.

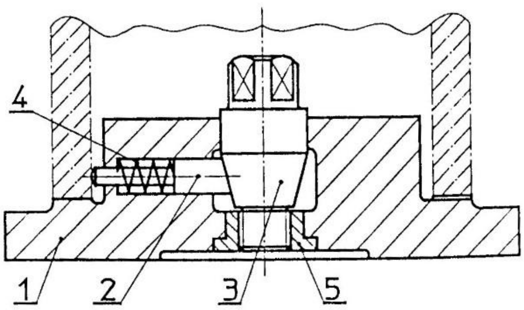


Figure 2-20. Special centring device [12]

BIDIRECTIONAL CENTRING USING VERTICES (CONES)

A Centring cones (turning cones) achieve a precise bidirectional centring (Figure 2-21). Their use is very common for long workpieces of a solid-body type, primarily on lathes and grinding machines. Prior to clamping, a tapered bore corresponding to the tip angle must be made in the workpiece, known as a tip slot. The tip angle is most often 60º or 90º. The axial location of the workpiece is influenced by the scale of the depth of the tip slot. Therefore, if a high precision axial locating is also required, a so-called deflection taper can be used (Figure 2-22). In this solution, the tip is supported by a spring and moves axially and the workpiece impacts on a fixed support.

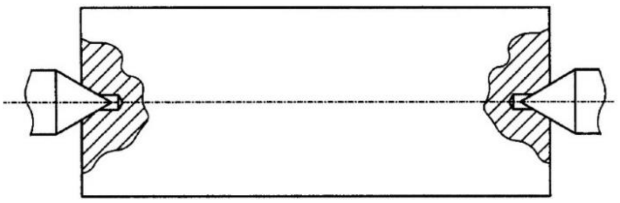


Figure 2-21. Bidirectional centring with stationary centring cones

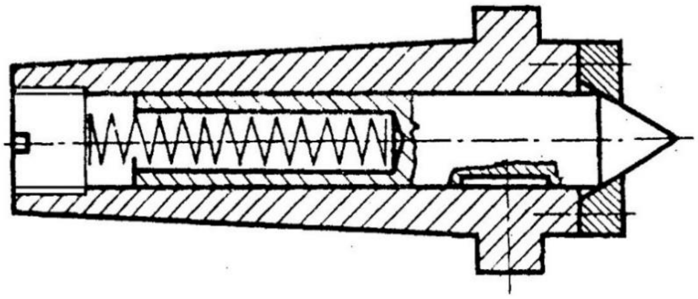


Figure 2-22. Deflecting centring cone

2.1.6 THE PROBLEM OF LOCATING

2.1.6.1 LOCATING FAULT WHEN USING MANDRELS AND PINS

Cylindrical mandrels and pins do not provide accurate centring because, in order to fit all workpieces, the mandrel diameter has to match the lower limit of the bore size and some clearance is also required to ensure smooth fitting of the workpieces. The expected eccentricity equals half the large clearance (Figure 2-23).

$$e = \frac{J}{2}$$

WHERE: J large clearance between pin and bore

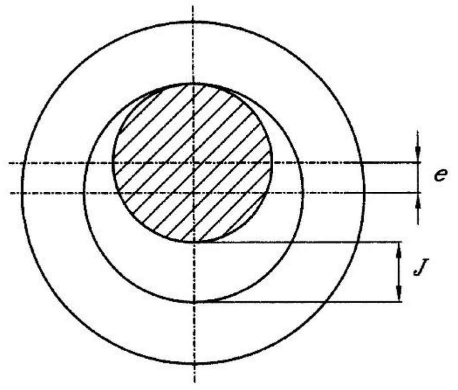


Figure 2-23. Locating mistake when using spikes and pins

2.1.6.2 VARIANTS OF TWO-PIN SIDE LOCATING AND MAGNITUDE OF POSITIONING ACCURACY ERROR

A mathematical relationship between the size and axial spacing of the holes used for locating and the locating accuracy error can be described for the different variants of the two- pin side locating. From these relationships, it is easy to see that, given the same accuracy of machining the bores used as the base surface, the magnitude of the locating accuracy error will be different for different versions of the two- pin side locating. For simplicity of illustration, we assume that the diameters (D) and tolerances (T) of the bores are the same, and the axial tolerance of the bores is ±T L (Figure 2-24.). The possible errors of the tool holder are not considered this time. The analysis of the possible locating errors for the two main directions (x, y) is illustrated in Figure 2-25.

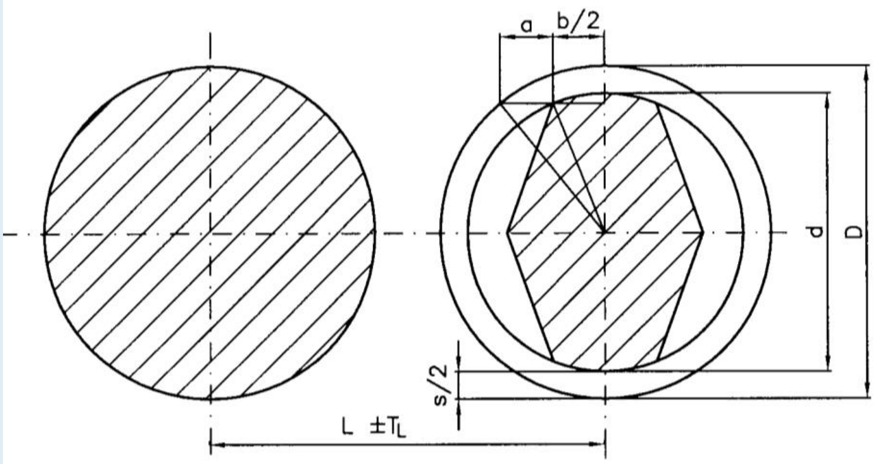


Figure 2-24. Flattened pin

For p21 and p22, the locating error can be easily determined from Figure 2-25.

For p23 and p24, one of the pin is flattened. The magnitude of the flattening is determined in practice by the formula b=0,2·D. The minimum clearance between the cylindrical part of the flattened pin and the bore can be determined using the notation in Figure 2-24, using the following relationship [8], [19]:

$$\left(\frac{d}{2}\right)^2 - \left(\frac{b}{2}\right)^2 = \left(\frac{D}{2}\right)^2 - \left(\frac{b}{2} + a\right)^2$$

BY NEGLECTING THE SECOND-ORDER SMALL MEMBERS, THE EQUATION CAN BE WRITTEN IN THE FOLLOWING FORM:

$$\left(\frac{d}{2}\right)^2 \approx \left(\frac{D}{2}\right)^2 - b \cdot a$$

$$b \cdot a = \left(\frac{D}{2} + \frac{d}{2}\right) \cdot \left(\frac{D}{2} - \frac{d}{2}\right),$$

AND THE MEMBERS IN PARENTHESES CAN BE TRANSFORMED AS THE FOLLOWING:

$$\frac{D}{2}+\frac{d}{2}=\frac{D}{2}+\frac{D}{2}-\frac{s}{2}=D-\frac{s}{2}$$

WHERE S - the minimum game

$$\frac{D}{2}-\frac{d}{2}=\frac{s}{2}$$

THIS CAN BE WRITTEN BY SUBSTITUTING:

$$b\cdot a=\left(D-\frac{s}{2}\right)\cdot\frac{s}{2}=D\cdot\frac{s}{2}-\frac{s^2}{4}\approx D\cdot\frac{s}{2}$$

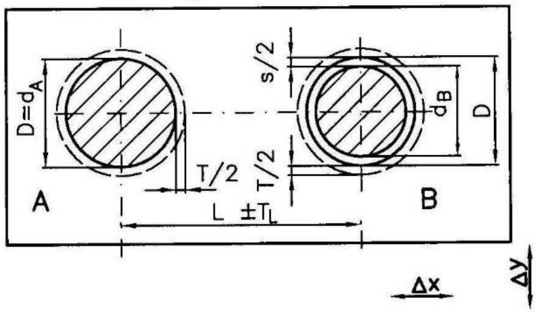
HENCE THE MINIMUM CLEARANCE:

$$\frac{s}{2}\approx\frac{b\cdot a}{D}\approx 0{,}2\cdot a\,,\qquad \text{so}\qquad s=\frac{2}{5}\cdot a$$

Variants of two pin locating

Pin size and locating mistake

p 2 1



Bore A

$d_A = D; \quad J = T$

$$\Delta x = \frac{J}{2} = \frac{T}{2}$$

$$\Delta y = \frac{T}{2}$$

Bore B

$d_B = D\text{-}s; \quad s = 2T_L$

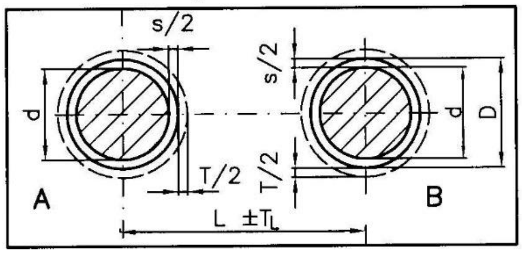
$J = T + s = T + 2T_L$

$$\Delta x = \frac{J}{2} = \frac{T + 2T_L}{2}$$

$$\Delta x = \frac{T}{2} + T_L$$

$$\Delta y = \frac{T}{2} + T_L$$

p 2 2



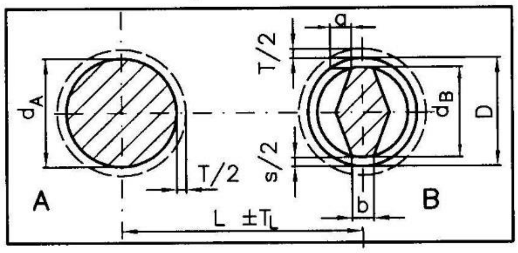
$d_B = d_A = d = D\text{-}s$

$s = T_L$

$J = T + s = T + T_L$

$$\Delta x = \Delta y = \frac{J}{2} = \frac{T}{2} + \frac{T_L}{2}$$

p 2 3



Bore A

$d_A = D; \quad J = T$

$$\Delta x = \frac{J}{2} = \frac{T}{2}$$

$$\Delta y = \frac{T}{2}$$

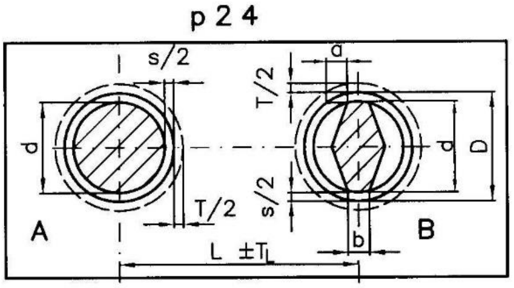
Bore B

$d_B = D\text{-}s; \quad s = \frac{2}{5}a;$

$a = T_L; \quad J = T + s$

$$\Delta x = \frac{T}{2} + T_L$$

$$\Delta y = \frac{J}{2} = \frac{T}{2} + \frac{T_L}{5}$$



$$d_A = d_B = d = D - s$$

$$s = \frac{2}{5}a\,; \quad a = T_L - \frac{s}{2}$$

$$s = \frac{2}{5}\left(T_L - \frac{s}{2}\right) = \frac{T_L}{3}\,; \qquad J = T + s$$

$$\Delta x = \frac{J}{2} = \frac{T}{2} + \frac{T_L}{6}$$

$$\Delta y = \frac{J}{2} = \frac{T}{2} + \frac{T_L}{6}$$

$$\Delta x = \frac{J}{2} + T_L = \frac{T}{2} + \frac{7T_L}{6}$$

$$\Delta y = \frac{J}{2} = \frac{T}{2} + \frac{T_L}{6}$$

NOTATIONS:

T - bore tolerance

D - lower size of the bores

s - minimum clearance

J - large clearance

±T_L - axial tolerance of the bores

2.1.6.3 MAGNITUDE OF LOCATING MISTAKES WHEN USING FIXED PRISMS

When cylindrical parts are placed on a prism, the locating errors of the feature points of the component as a function of size dispersion and prism angle can be expressed analytically. Using the notations in Figure 2-25, the displacement of the feature points of the centre and outer contour due to size dispersion can be written as the following relationships:

The difference between the upper and lower limits of the diameter is the diameter tolerance

$$T = D_{max} - D_{min}$$

The difference in location of the centre axis in the upper and lower limits:

$$e = \overline{AO_1} - \overline{AO_2}$$

$$\overline{AO_1} = \frac{D_{max}}{2 \cdot sin\frac{\alpha}{2}},$$

$$\overline{AO_2} = \frac{D_{min}}{2 \cdot sin\frac{\alpha}{2}}$$

$$e = \frac{T}{2} \cdot \frac{1}{sin\frac{\alpha}{2}}$$

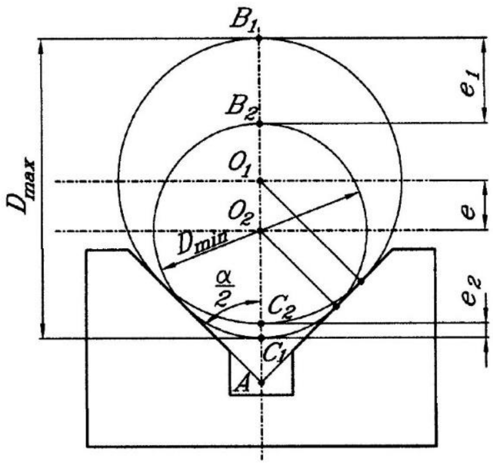


Figure 2-25. Offset of the feature points of the centre and the outer contour

In a similar way for e1 and e2: $e_1 = e \cdot \left(1 + sin\frac{\alpha}{2}\right), \quad e_2 = e \cdot \left(1 - sin\frac{\alpha}{2}\right)$

The prism angle is most often α = 90°, and with this value the characteristic offsets:

$$e = 0{,}7\,T \qquad e_1 = 1{,}21\,T \quad e_2 = 0{,}2\,T$$

It is easy to see that, if it is not necessary to ensure that the centre plane is in the same location, the values of the offsets just analysed will be smaller if two tangential planes are used for locating instead of a prism (Figure 2-26):

$e = 0{,}5\,T$
$e_1 = T$
$e_2 = 0$

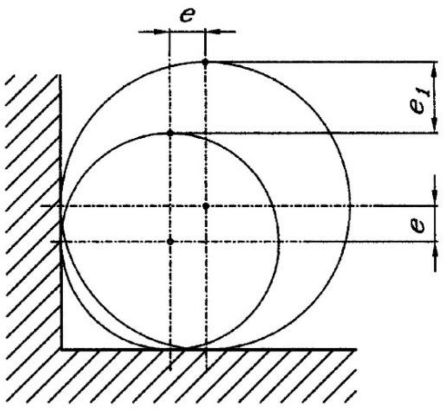


Figure 2-26. Offset of the feature points of the centre and the outer contour when using tangential planes

2.2 THE LOCATING ELEMENTS

The elements of workpiece holder fixtures that determine the location of the workpiece in the fixture are called seats. Typical seat configurations can be used to implement the described methods of locating. Seats can be roughly subdivided according to the role they fulfil:

_simple seats, which define an actual point on the workpiece, and
_centring seats, which define the centre plane or several centre planes of the workpiece.

In general, the elements of the fixture can be typified, and the design and dimensions of most of them are given in standards. They can therefore be pre-manufactured in series and purchased from specialised companies. This also applies, of course, to seats. Seats are generally made of non-alloy tool steel (C 80 U) or of case hardenable steel, which must be hardened to a hardness of 56 ± 2 HRc to increase wear resistance.

2.2.1 SIMPLE SEATS AND SUPPORTS

Simple seats, or shorten seats, are usually used in the case of flat base surfaces. They may be rigid (fixed) or movable.

2.2.1.1 RIGID SEATS

Rigid seats can be subdivided into integrated and mounted seats according to their installation.

INTEGRATED SEATS

Integrated seats are formed on the fixture body itself, so they are formed by machining the body from a single piece (Figure 2-27). Such a design has significant disadvantages: (1) the machining cost of the body is significantly increased, (2) the seats are difficult to repair (not easy to replace) when worn or damaged, (3) the material requirements of the body are increased.

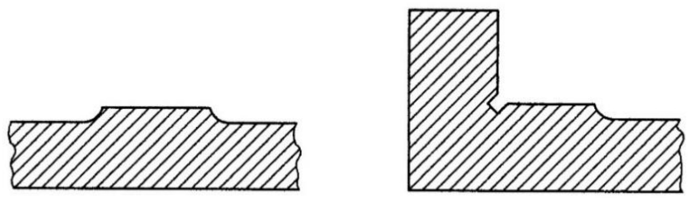


Figure 2-27. Integrated seats

MOUNTED SEATS

Mounted seats can be typified and prefabricated in series. They are integrated into the body of the fixture by screws or by tight fitting. After integration, flat grinding is sometimes used to ensure flatness. They can be used as both plane located and side located seats. Their interchangeability is a significant advantage. They are most often made of non-alloy tool steel and are hardened to increase their wear resistance. Mounted rigid seats can be subdivided into pin, cylindrical and flat seats according to their shape.

Pin seats have the simplest design and are very common in fixture building. They are relatively simple to manufacture but are also widely available commercially.

According to the shape of the part in contact with the workpiece surface, the design can be (2-28):

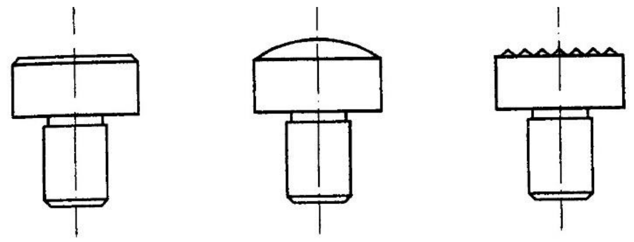


Figure 2-28. Design of pin seats

_flat surface, used when the base surface is already machined or when a cylindrical or spherical surface has to be supported,
_convex-headed, which is used when the base surface is rough (cast, forged),
_notched head, used for rough work to increase the friction between the workpiece and the seat.

Pin seats are installed with a tight fit in the fixture body (Figure 2-29).

CYLINDRICAL SEATS are defined as pin seats whose cylindrical surface is used for endwise locating or guidance. They differ from pin seats in that the cylindrical surface of the head section is also ground to exact dimensions (Figure 2-35

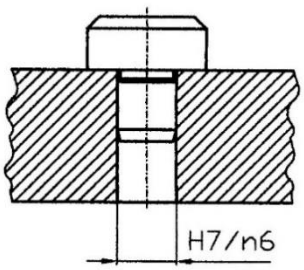


Figure 2-29. Installation of pin seats

FLAT SEATS can only be used where the base surface is contoured. They are installed with screws (Figure 2-30). They can be made in several versions, some of which are standardised or typified and are commercially available (Figures 2-31).

Seats with a smooth working surface should be avoided when they are installed in a horizontal location, because this can cause chips and dirt to accumulate on them and lead to incorrect locating. Seats with chip collecting ditches (grooves) in the horizontal location are recommended, as chips and dirt are deposited in the chip collecting ditches when the workpiece is positioned (offset) (Figure 2-31). The use of flat seats is particularly justified in cases where the workpiece has to be slid into the right location from the side.

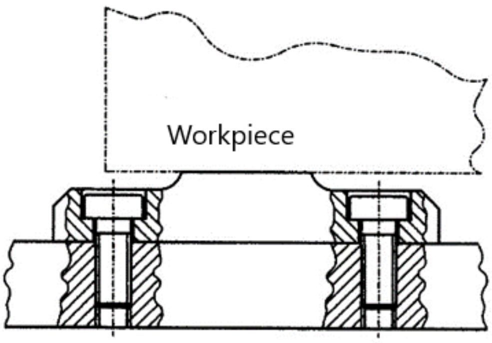


Figure 2-30. Installation of flat seats

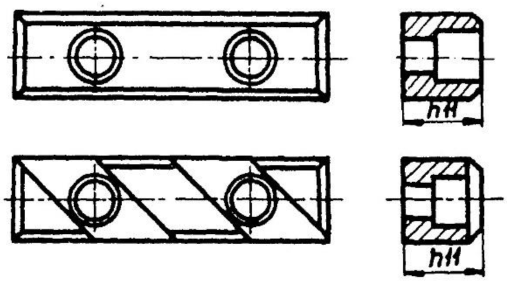


Figure 2-31. Flat seats

In some cases, dual-function flat seats can also be used, which, in addition to plane locating, also perform a side locating function (Figure 2-32). This reduces the number of elements of the fixture.

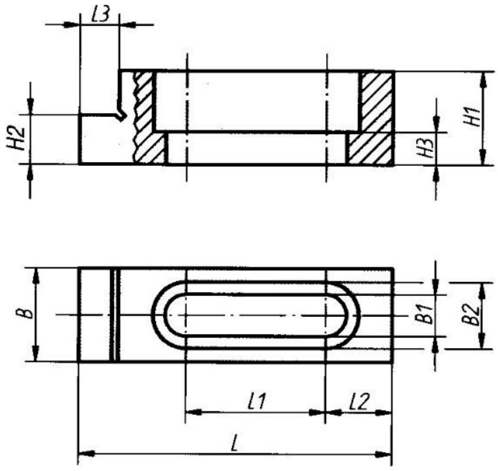


Figure 2-32. Dual-function flat seat

2.2.1.2 MOVING SEATS

Moving seats are significantly less rigid than fixed seats. It is therefore only used when absolutely necessary. They can be divided into adjustable and self-adjusting seats.

The use of ADJUSTABLE SEATS (Figures 2-33) is justified in two cases: (1) when one device is intended to accommodate several workpieces of slightly different sizes, (2) when a significant variation in the size of the prefabricated part is expected.

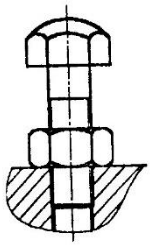


Figure 2-33. Adjustable seat

SELF-ADJUSTING SEATS allow the workpiece to be lay-up at more than three points without over-positioning (Figure 2-34). Support at several points may be justified by the shape or low rigidity of the workpiece. The adjusting is considered as a support point from the point of view of locating. Self-adjusting seats can only be used in combination with rigid seats, so plane locating is determined with two rigid seats and one adjustable seat.

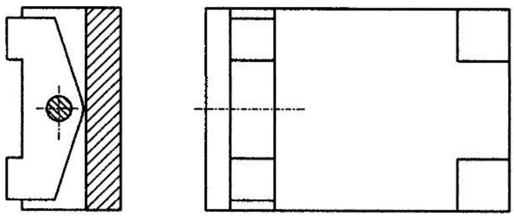


Figure 2-34. Theoretical solution for a self-adjusting seat

The design of the SUPPORTS is the same as for adjustable seats (Figure 2-33), but the important difference is that the supports are not involved in the locating. They are adjusted afterwards, to the surface of the workpiece, which has already been located. Their use is justified for workpieces with low rigidity.

2.2.2 CENTRING SEATS

CENTERING PINS (SEATS) are designed and sized to fit the bore of the workpiece. The length of the pin has to be selected in a way that it is in contact with only a short section of the cylindrical surface of the workpiece.

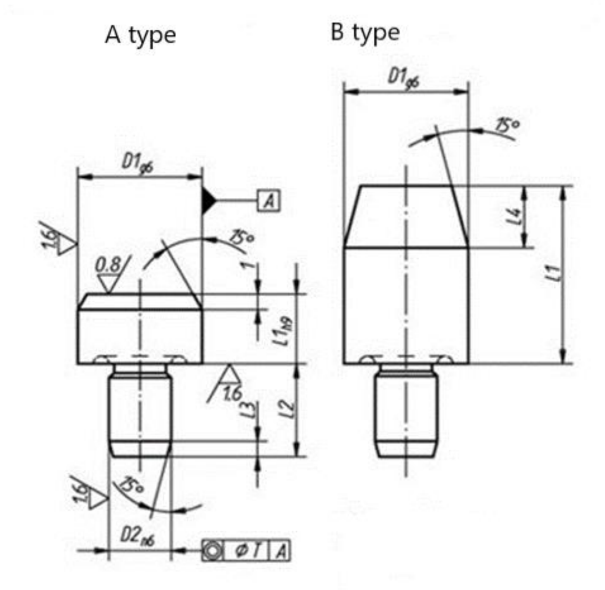


Figure 2-35. Centring pins

Figure 2-35 illustrates some common solutions. The material of the pins is usually case hardened steel. Centring pins can be purchased ready-made in the sizes available.

The design of a FLATTENED OR ORIENTED PIN, except for the flattening, is similar to the design of the centring pin (Figure 2-36).

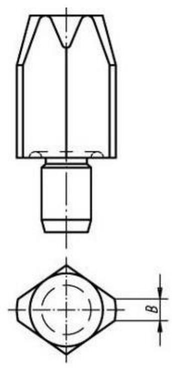


Figure 2-36. Oriented pin

In the case of large bores, the centring element is disc-shaped. It is always manufactured for the task in hand, and then built into the body of the fixture with a fitted pin part and screws (Figure 2-37).

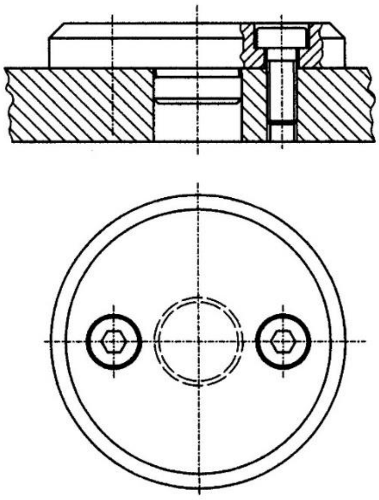


Figure 2-37. Installation of a centring disc

PRISMS can be made in short and long versions. They are usually installed with screws and joint pins (Figure 2-38). Instead of a long prism, two short prisms can be used.

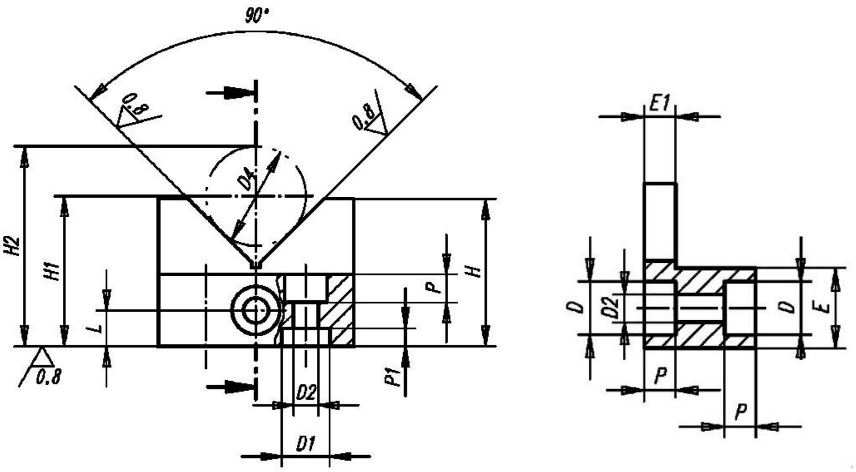


Figure 2-38. Short prism (Kipp)

3. CLAMPING OF WORKPIECES

3.1 BASIC CONCEPTS

Workpiece clamping is the act of fixing the workpiece so that it cannot be moved from the seats by chipping and other forces during machining. The elements of the fixture with which the clamping is performed are called clamping elements. A distinction is made between main and assisted clamping (Figure 3-1). The function of the assist clamp is to press the workpiece onto the seats prior to the main clamp. In most cases, it works with an elastic element (spring). They are not necessarily a necessary part of the machine, but their use usually makes workpiece changes faster.

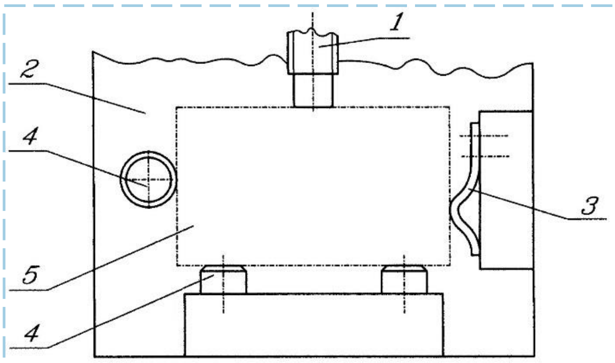


Figure 3-1. Assisted clamping with flat spring

1) *clamping screw*
2) *fixture body*
3) *flat spring as assist clamp*
4) *seats*
5) *workpiece*

3.1.1 POSITIONING OF THE CLAMPING FORCE

Based on the line of action of the clamping force, the clamping can be perpendicular to the plane locating surface or parallel to the plane locating surface (lateral clamping). In the case of perpendicular clamping, the clamping surfaces are located on the sides adjacent to the plane locating surface or on the opposite side, while in the case of lateral clamping, the clamping surfaces are always located on the sides adjacent to the overlying surface (Figure 3-2).

Another important characteristic of the clamping is the number of points at which clamping occurs. According to the number of clamping points, a distinction can be made between one-, two-, three- and four-point clamping.

The location of the clamping should be chosen so that the closing force is applied through the plane locating surface. The transfer of force should preferably be through the seats (Figure 3-3).

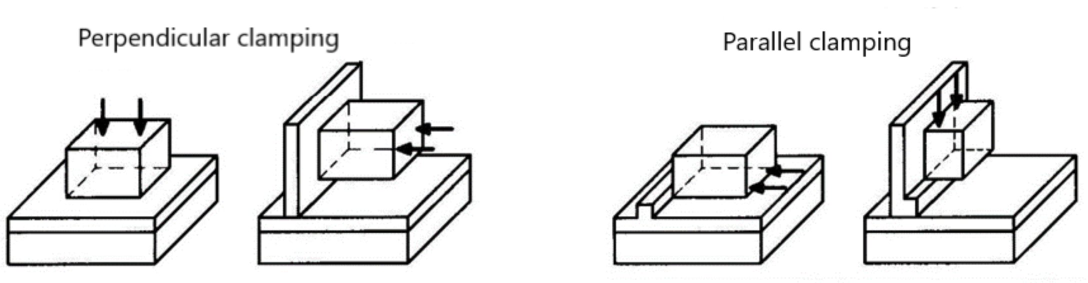
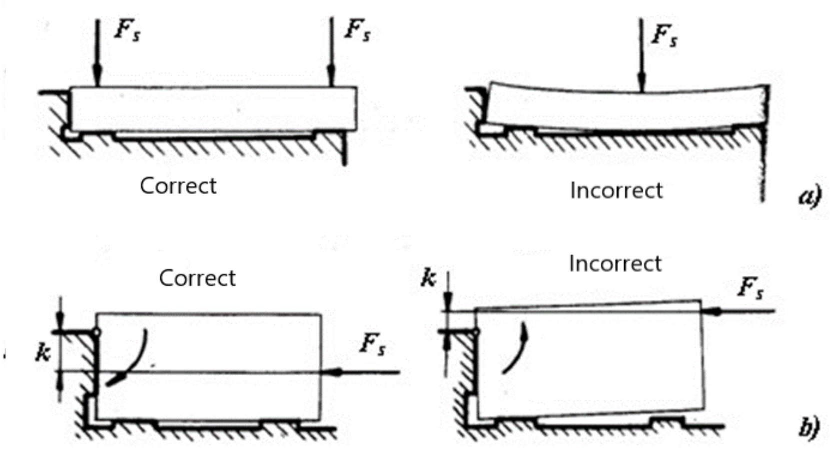


Figure 3-2. Perpendicular and parallel clamping [19]



a) perpendicular clamping

b) lateral clamping

In the case where it is not possible to transfer force through the seats, the clamping force has to be positioned within the plane locating limit line (Figure 3-4).

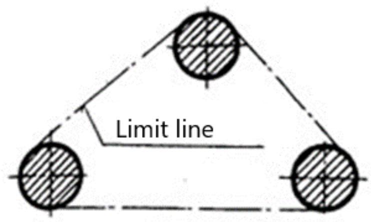


Figure 3-4. Plane locating limit line

The chipping process and the fixture should preferably be designed in such a way that the applied chipping force is applied to the seat to clamp the workpiece (Figure 3-5).

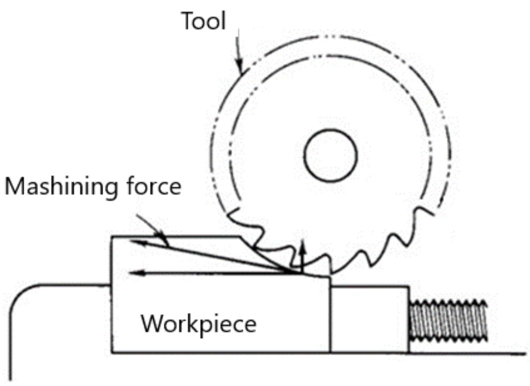


Figure 3-5. Clamping on the seat [11]

3.1.2 DETERMINING THE MAGNITUDE OF THE CLAMPING FORCE REQUIRED

During machining, the chipping or forming forces are acting on the workpiece, from where they are transmitted to the fixture and then through the fixture body to the machine tool. The line of action and the magnitude of the chip force (Fc), feed force (Ff) and passive force (Fp) resulting from the machining operation can be determined according to the machining modes. The machining force (F) for the design of the fixture, is most often defined as the product of the chipping force (Fc) and a force multiplication factor:

$$F = F_c \cdot C_1 ,$$

WHERE: C_1 tempirical force multiplication factor (Table 3-1),

Table 3-1. Values of the force multiplication factor [4]

Chipping mode	C_1
Turning and drilling	1,2
Milling and grinding	1,4
Planing	1,6
Engraving	1,8

Three typical cases can be distinguished according to the line of action and direction of the applied cutting force (F) and clamping force (Fs) (Figure 3-6):

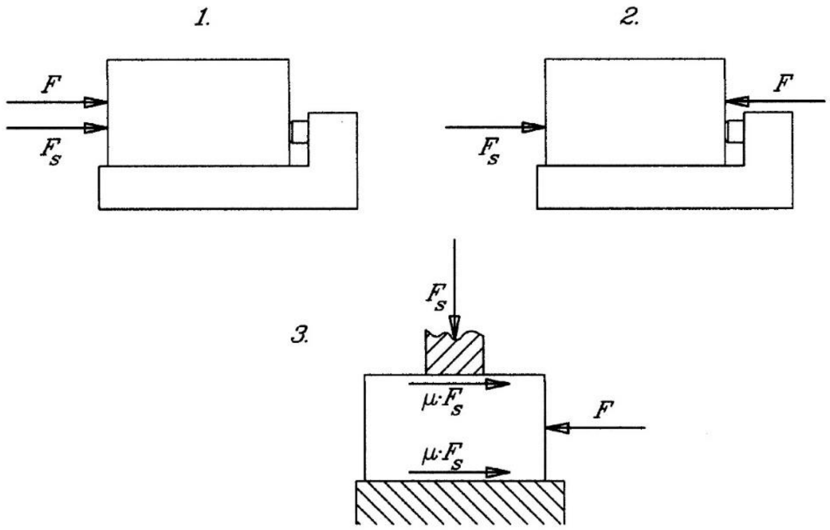


Figure 3-6. Typical cases of clamping force application

1. The direction of the clamping force and the direction of the chipping force are the same and clamp the piece into the seat. In this case the clamping force can be very small.

2. The clamping force and the chipping force have the same line of action but are in opposite directions. In this case the value of the clamping force is:

$$F_s = s \cdot F$$

WHERE:

s = 2 safety factor. This takes into consideration possible vibrations and the tilting effect due to the torque of forces with different lines of action. [4].

3. The clamping force is perpendicular to the chipping force. Friction on the contact surfaces holds the piece in place. A condition of force balance:

$$F_s \cdot \mu_1 + F_s \cdot \mu_2 = s \cdot F \text{ , or } \qquad F_s = \frac{s \cdot F}{\mu_1 + \mu_2}$$

WHERE: μ_1 friction coefficient between the seat and the workpiece

μ_2 friction coefficient between the clamping element and the workpiece

If we assume that $\mu_1 = \mu_2$ =0,1 the value of the clamping force $F_s = \frac{2}{0{,}1+0{,}1} \cdot F = 10 \cdot F$ can be taken.

When the workpiece is clamped in a chuck, the torque of the chipping force is balanced by the torque of the forces due to friction between the clamping jaws and the workpiece (Figure 3-7):

$$\mu \cdot F_s \cdot \frac{D}{2} \cdot z = s \cdot M \text{ , ill.} \qquad F_s = \frac{2 \cdot s \cdot M}{\mu \cdot D \cdot z}$$

WHERE: *M* the torque from the chipping process

D is the clamping diameter

z is the number of clamping jaws

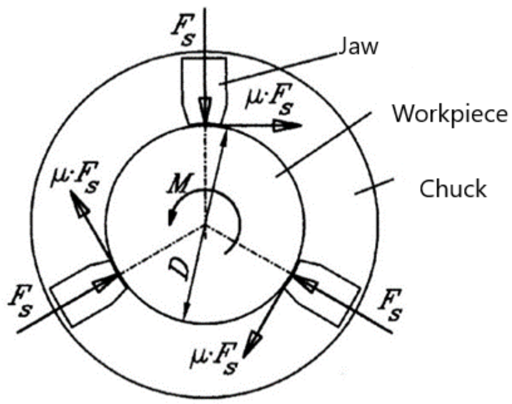


Figure 3-7. Workpiece clamped in the chuck

3.2 MANUAL CLAMPING AND ITS COMPONENTS

Main parts of the clamping devices (Figure 3-8):
(1) force application elements (levers, handles),
(2) force increasing elements (screws, wedges, etc.),
(3) force transmitting elements (levers, pressure plates, etc.).

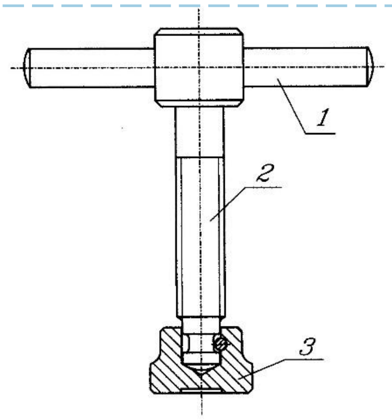


Figure 3-8. Main parts of clamping devices

1- force exerting element
2- force increasing element
3- force transmitting element

As a force multiplier or force increasing element, some form of self-locking incline is most commonly used (wedge, screw, excentre). In addition, various lever mechanisms can be used, and sometimes a combination of self-locking incline and lever mechanism is used. Figure 3-9. illustrates the most commonly used force increasing solutions.

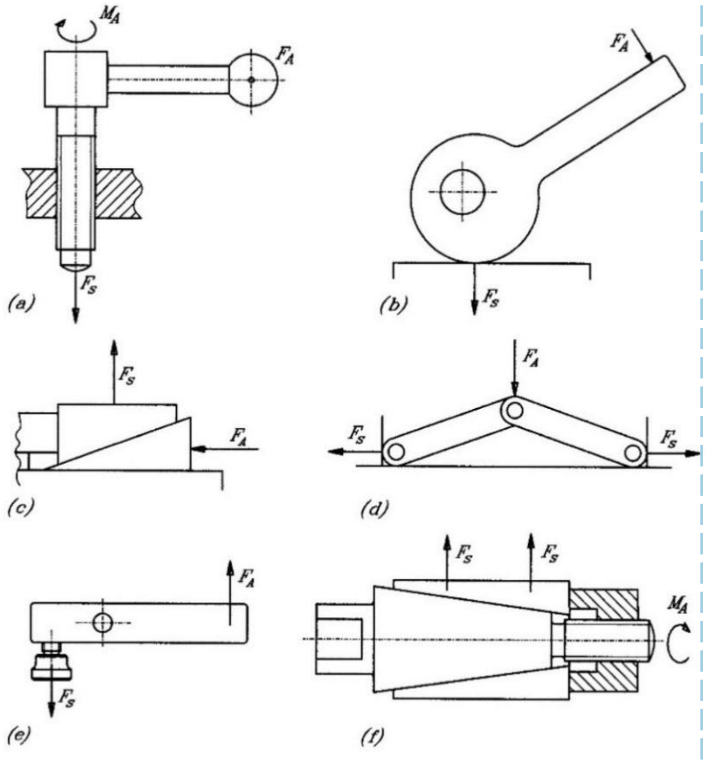


Figure 3-9. Commonly used force increasing solutions: a) screw, b) excentre c) wedge, d) lever mechanism, e) two-arm lift, f) screw and wedge combination [11]

3.2.1 WEDGE CLAMPING

Wedge clamping is rarely used directly, but is often used in various clamping mechanisms. It is important to understand it because it is where self-locking is most easily analysed, and the principle of self-locking slope is also used in other clamping methods (screw clamping, clamping excentre).

THE FORCE OF WEDGE CLAMPING

As a first approach, let us examine the force effects without taking friction into account (Figure 3-10(a)).

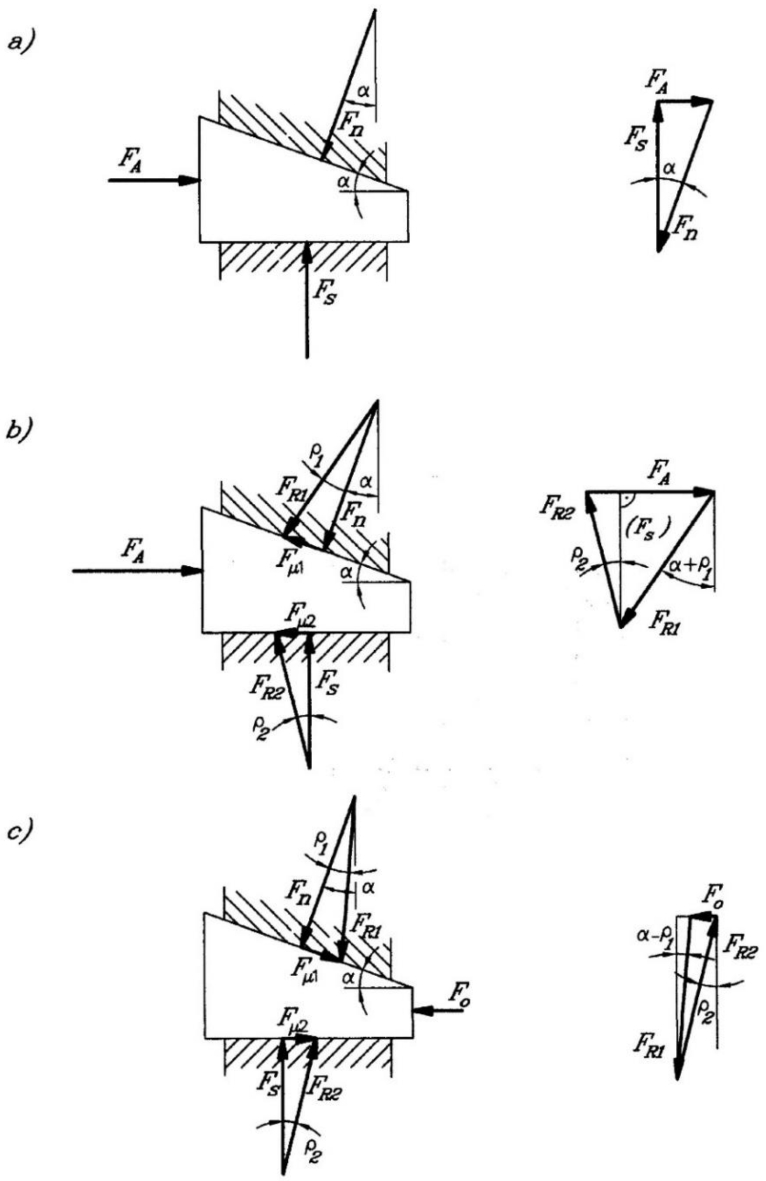


Figure 3-10. The force of wedge clamping

a) without taking friction into account

b) with taking friction into account

c) loosening

The value of the required clamping force, determined as described in section 3.1.2, should be taken as a starting point. The wedge is subject to three forces, the equilibrium condition (triangle of forces) can be written down as follows:

$$F_A = F_s \cdot tg\alpha \qquad F_n = \frac{F_A}{\sin\alpha} = \frac{F_s}{\cos\alpha}$$

WHERE:

- F_A the external (activating) force acting on the wedge
- F_s is the clamping force on the workpiece
- F_n is the perpendicular force acting on the slope surface
- α is the wedge angle

In reality, of course, there is friction and, as a result, self-locking can occur, which means that the tightness is not released even after the F_A force is released (Figure 3-10(b)).

In general, the working surfaces have different values of friction coefficient (μ1, μ2) and corresponding friction forces:

$$F_{\mu 1} = \mu_1 \cdot F_n\,, \qquad F_{\mu 2} = \mu_2 \cdot F_s$$

The friction half cone angles are:

$$tg\rho_1 = \frac{F_{\mu 1}}{F_n} = \mu_1 \qquad tg\rho_2 = \frac{F_{\mu 2}}{F_s} = \mu_2$$

The forces acting on the working surfaces taking friction into account:

$$F_{R2} = \frac{F_s}{\cos\rho_2} \quad ,$$

$$F_{R1} = \frac{F_n}{\cos\rho_1} = \frac{F_s}{\cos(\alpha+\rho_1)}$$

Required value of the activating force based on the force triangle:

$$F_A = F_{R1}\cdot\sin(\alpha+\rho_1) + F_{R2}\cdot\sin\rho_2 \,.$$

If we substitute the expression for FR1 and FR2 into the above formula, we obtain the value of the activating force as a function of the required clamping force:

$$F_A = F_s\cdot[tg(\alpha+\rho_1) + tg\rho_2]\,.$$

It is also important to consider the condition of self-locking (Figure 3-10(c)). Wedge clamping is self-locking if the release is only obtained under the action of some force (Fo). The release force can be determined in a similar way as the activation force, taking into consideration that the direction of the friction forces is now changed:

$$F_{R2} = \frac{F_s}{\cos\rho_2} \quad , \qquad F_{R1} = \frac{F_s}{\cos(\alpha-\rho_1)}$$

From the force triangle (Figure 3-10(c)):

$$F_o = F_{R2}\cdot\sin\rho_2 - F_{R1}\cdot\sin(\alpha-\rho_1) \text{ , or}$$

$$F_o = F_s\cdot[tg\rho_2 - tg(\alpha-\rho_1)]$$

The limit case of self-locking can be considered as the case when Fo = 0. By analysing the above expression, it can be concluded that this happens when the term in square brackets becomes zero, or:

$$tg\rho_2 - tg(\alpha - \rho_1) = 0, \qquad tg\rho_2 = tg(\alpha - \rho_1)$$

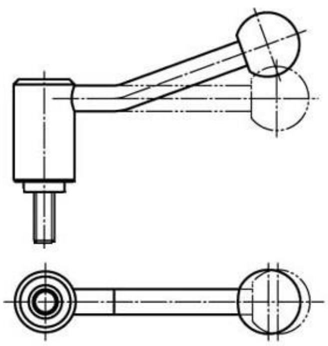
Assuming that $\rho_1 = \rho_2 = \rho$, and for small angles the tangent of the angle is approximately equal to the value of the angle in radians, the above condition can be written in the following form:

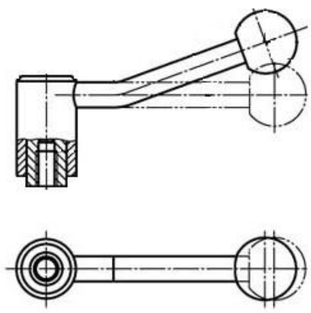
$$\alpha = 2\rho$$

Thus, the wedge angle has to be less than or at most equal to twice the friction semi-cone angle. In practice, the material of the friction surfaces is steel and the value of the coefficient of friction is $\mu = tg\rho = 0{,}1$. This corresponds to $\rho = 5{,}71^o$ and the corresponding limit of the wedge angle is $\alpha = 11{,}42^o$. This corresponds to a slope of approximately1:5, in practice a much smaller value is used, mostly 1:10 or 1:20.

3.2.2 BOLT CLAMPING

The use of bolt clamping is relatively common, mainly due to the fact that bolts can be used to exert a high tightening force and that standard bolts are all self-locking, which is important when tightening. The most common standard threads used are metric threads, metric fine threads and trapezoidal threads. A distinction is made between direct and indirect bolt clamping.


a)


b)

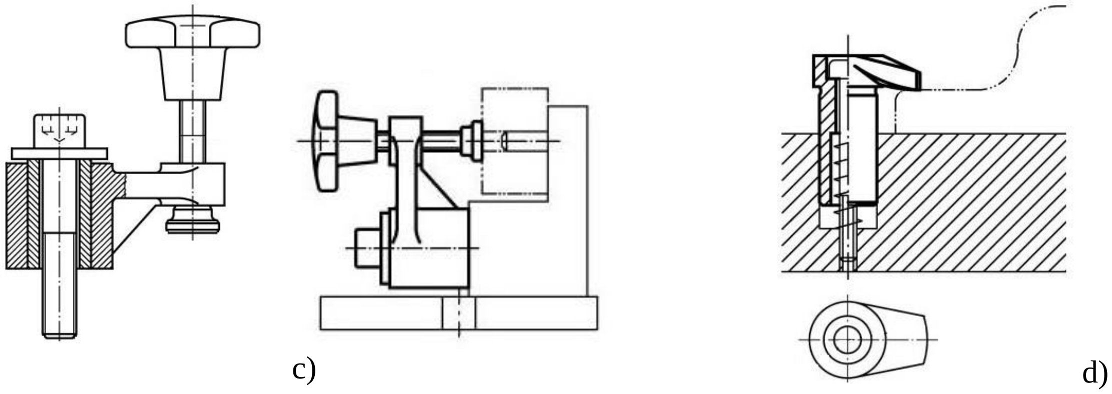


Figure 3-11. Direct bolt clamping (Kipp)

a) lever clamping bolt, b) lever clamping nut, c) turnable clamping bolt, d) hook clamping rod

3.2.2.1 DIRECT BOLT CLAMPING

Direct bolt clamping is when the clamping force generated by the bolt thread is used directly for clamping. The simplest version is the simple clamping bolt or clamping nut, but also includes the turnable clamping bolt and the hook clamping iron (Figure 3-11).

THE POWER ACTION OF BOLT CLAMPING

An activating force (FA) and a clamping lever are used to create an activating torque (MA) (Figure 3-12). This exerts a tangential force (Ft) on the thread centre diameter:

$$M_A = F_A \cdot l_A = F_t \cdot \frac{d_2}{2} \quad \text{or} \quad F_t = \frac{2 \cdot M_A}{d_2} = \frac{2 \cdot F_A \cdot l_A}{d_2}$$

WHERE: F_A is the activating force. Do not exceed 150 N in case of manual clamping.

l_A is the length of the lever

d_2 is the centre diameter of the thread

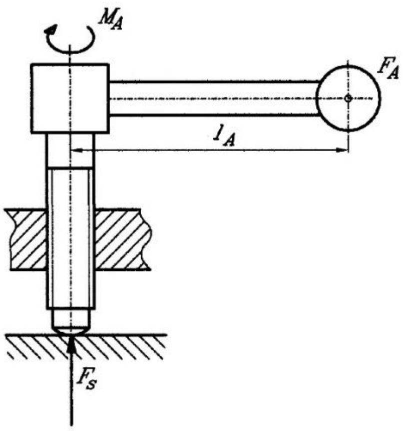


Figure 3-12. Direct bolt clamping

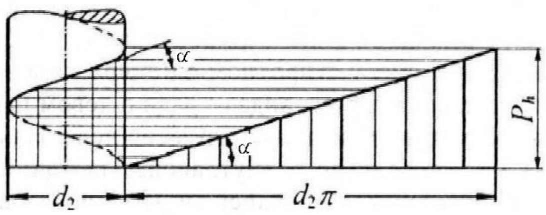


Figure 3-13. Derivation of the bolt thread

The clamping force is determined on the basis of the relationship derived for wedge clamping, since the bolt line is nothing more than a slope that is twisted onto a cylinder (Figure 3-13). Based on the forces acting on the wedge or spindle thread and the vector diagram (Figure 3-14), the following relationship can be written:

$$F_s = \frac{F_t}{tg(\alpha + \rho_n)} = \frac{2 \cdot F_A \cdot l_A}{d_2 \cdot tg(\alpha + \rho_n)}$$

WHERE: α is the thread pitch angle,
ρ_n modified or reduced friction half cone angle

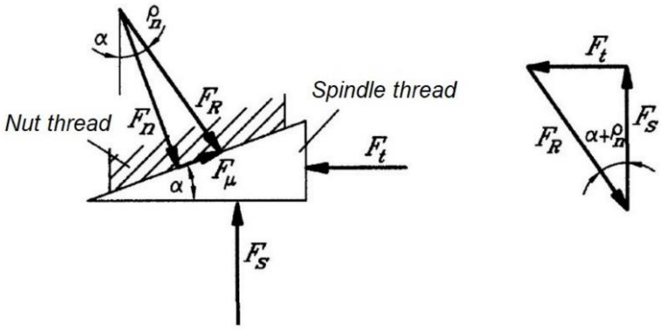


Figure 3-14. Force action of bolt clamping

The significance of the modified or reduced friction half cone angle (ρn) is that it takes into account the profile angle of different thread profiles. This is because the normal force perpendicular to the thread side causes friction and it is easy to see that the normal force is not only a function of the thread pitch angle but also of the profile angle (Figure 3-15).

Friction force for a flat thread:

$$F_\mu = F_n \cdot \mu,$$

while for metre thread or trapezoidal thread:

$$F_\mu = F_n^{'} \cdot \mu = F_n \cdot \frac{\mu}{cos\frac{\beta}{2}} = F_n \cdot \mu_n$$

$$\mu_n = \frac{\mu}{\cos\frac{\beta}{2}}$$

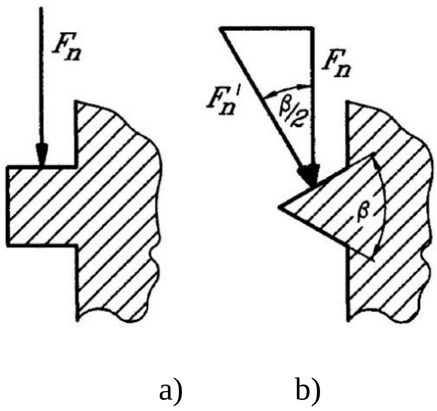


Figure 3-15. Normal force

WHERE: μ coefficient of friction

F_n' force perpendicular to the side of the thread (Figure 3-15)

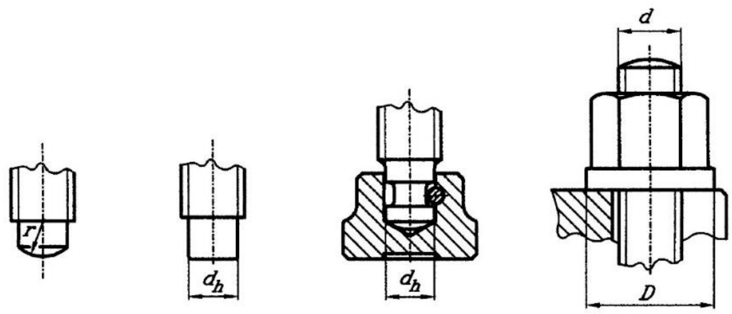
μ_n reduced friction coefficient, $\mu_n = tg\rho_n$

a) for flat threads
b) for metre thread

The value of the clamping force is influenced not only by the angle of thread pitch and the reduced friction half cone angle, but also by the friction losses at the point of force transmission. Part of the activating torque is used by the "friction torque" at the point of force transmission and the actual effective torque on the bolt is the difference between the two:

$$M_{cs} = M_A - M_\mu$$

The value of the torque loss depends largely on the method of force transmission. In practice, four typical cases of force transmission can be distinguished: (1) spherical bolt end, (2) cylindrical bolt end, (3) pressure hammer, (4) nut. The cases listed are shown in Figure 3-16.



3-16. Typical cases of power transmission

n the case of a spherical bolt end, the force is theoretically transmitted at one point. Therefore, in this case the torque loss is zero. It should be noted, however, that in the case of spherical and flat surface contact, Herz stress occurs, as a result of which the theoretical contact at one point quickly changes to a small spherical slice-like surface and, in fact, when higher clamping forces are applied, clamping marks may remain on the workpiece (plastic deformation). In this case, the formula used in case (2) must be applied.

In the case of cylindrical screw endings, the contact area is circular with a diameter due to edge rounding

$$d_h^` = 0{,}8 \cdot d_h .$$

Where dh is the diameter of the cylindrical part of the screw end.

The torque of the friction force at the transmission of force:

$$M_{\mu} = F_s \cdot \mu_2 \frac{d_h^{`}}{4},$$

WHERE: μ2 is the friction coefficient between the screw end and the workpiece.

Taking this into account, the actual clamping force can be calculated from the balance of torques:

$$M_A = M_{cs} + M_{\mu}$$

$$F_A \cdot l_A = F_t \cdot \frac{d_2}{2} + F_s \cdot \mu_2 \cdot \frac{d_h^{`}}{4} = F_s \cdot \frac{d_2}{2} \cdot tg(\alpha + \rho_n) + F_s \cdot \mu_2 \cdot \frac{0{,}8 \cdot d_h}{4}$$

$$F_s = \frac{2 \cdot F_A \cdot l_A}{d_2 \cdot tg(\alpha + \rho_n) + \mu_2 \cdot 0{,}4 \cdot d_h}.$$

When using a pressure arm, the inner tapered surface of the pressure arm theoretically makes contact with the rounded end of the screw along a circumference. Roughly we can assume that the diameter of the circle is 0.8·dh, so the torque is:

$$M_{\mu} = F_s \cdot \mu_2 \frac{0{,}8 \cdot d_h}{2}.$$

And the clamping force can be calculated using the following formula:

$$F_s = \frac{2 \cdot F_A \cdot l_A}{d_2 \cdot tg(\alpha + \rho_n) + \mu_2 \cdot 0{,}8 \cdot d_h}.$$

When clamping with a nut, the contact is on a ring-shaped surface. With a slight simplification, it can be accepted that the torque of the friction force is given by the product of the centre radius of the annulus and the friction force: $M_{\mu} = F_s \cdot \mu_2 \frac{D_m}{2}$,

WHERE: $D_m \approx \frac{D+d}{2}$ the mean diameter of the contact surface

D is the outer diameter of the contact surface of the washer or nut,

d is the nominal diameter of the bolt.

μ2 is the friction coefficient between the nut and the workpiece, approximately

$\mu_2 = 0{,}25 \ldots 0{,}3$.

The value of the clamping force can be calculated using the following formula:

$$F_s = \frac{2 \cdot F_A \cdot l_A}{d_2 \cdot tg(\alpha + \rho_n) + \mu_2 \cdot D_m}.$$

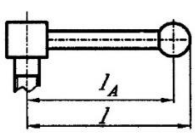
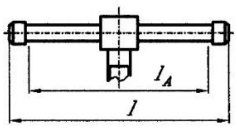
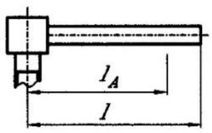
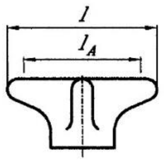
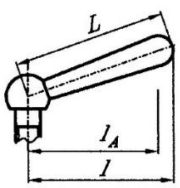
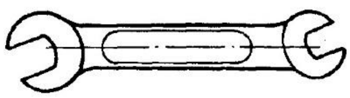
The value of the manual actuating force (FA) that can be calculated depends on the frequency of clamping and, of course, on the strength of the worker, the guide values are given in Table 3-1.

Table 3-1. Reference values for the exerted manual force [4].

Gender of the operator	Period between two clamps (min)	Manual force F_A (N)
Male	≥ 1	150
	< 1	100
Female	≥ 1	75
	< 1	50

The moment arm length (lA) is slightly less than the clamping arm working length (l) because the manual force cannot be applied directly to the end point of the clamping arm. For common moment arm designs, the relationships in Table 3-2 can be used to determine the moment arm.

Table 3-2. Determination of the moment arm [4].

Design of the clamping arm	The moment arm l_A	Design of the clamping arm	The moment arm l_A
	l_A		$l_A = l\text{-}20$ mm
	$l_A = l\text{-}50$ mm		$l_A = 0{,}75 \cdot l$
	$l_A = l\text{-}30$ mm		$l_A = 17{,}5 \cdot d$
			$l_A = 12{,}5 \cdot d$

3.2.3 EXCENTER CLAMPING

The excenter clamping is also based on the use of a self-locking slope (bent wedge), because the excenter disc is wedged between the excenter pin and the workpiece by manual torque. It allows a fast clamping, but the clamping force is significantly lower than with screw clamping. When clamping, it makes contact along a line with the work surface and therefore wears quickly. Due to its design, the clamping path is limited, twice the eccentricity (e). If the clamping location is subject to large dimensional dispersion or if strong vibrations occur during machining, eccentric clamping is not recommended. The clamping surface may be (1) a logarithmic spiral, (2) an Archimedes spiral, or (3) an eccentrically positioned circle. Because of its ease of manufacture, the use of a circular excenter is very common (Figure 3-17), but this has the disadvantage that the value of the clamping force is not constant over the entire clamping range, since the angle of attack (α) is variable: when the contact is at point A, the angle of attack is zero, at φ=90º rotation it is at maximum (αmax) and then decreases and then at point B it is zero again. Therefore only the middle part can be used for clamping (φ=60-120º).

The condition for self-locking is defined for the maximum angle of attack (αmax) (Figure 3-17) and can be formulated as the eccentric being self-locking as long as force or torque is applied to the release. The limit case is when the manual force is zero in equilibrium. Using the notations in Figure 3-17, the equilibrium of the torques can be written:

$$F_A \cdot l_A = F_s \cdot e + F_{\mu 1} \cdot \frac{D}{2} + F_{\mu 2} \cdot \frac{d}{2}$$

WHERE:

$F_{\mu 1} = F_s \cdot \mu_1$ friction force between the excenter and the workpiece,

$F_{\mu 2} \approx F_s \cdot \mu_2$ friction force between the excenter and the excenter pin

Taking the limiting case:

$$0 = F_s(e + \mu_1 \cdot \frac{D}{2} + \mu_2 \cdot \frac{d}{2}).$$

Since the clamping force cannot be zero, the expression in parentheses must be zero, so

$$0 = e + \mu_1 \cdot \frac{D}{2} + \mu_2 \cdot \frac{d}{2}.$$

If the friction factors are the same (for example, if the disc and pin are steel and the workpiece is steel), the above expression becomes simpler:

$$-e = \mu \cdot \frac{1}{2}(D + d) = \frac{1}{20}(D + d)$$

If we take the diameter relationship suggested in practice $d = \frac{1}{3} \cdot D$

$$-e = \frac{1{,}33}{20} D = 0{,}066 \cdot D \text{, or}$$

$$|e| \le \frac{D}{15}.$$

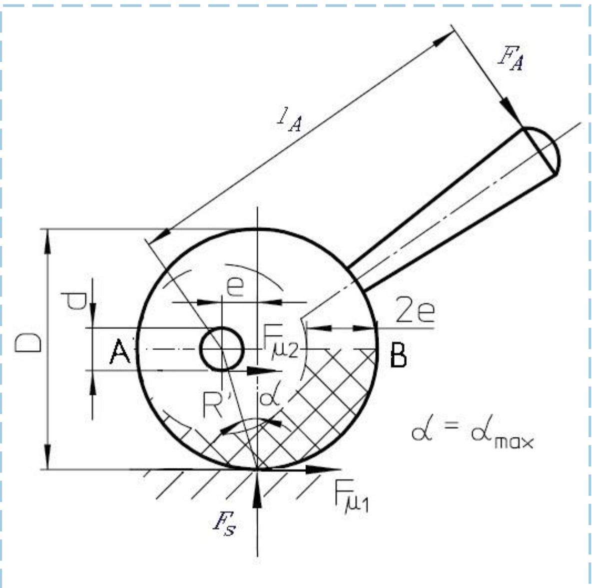


Figure 3-17. Excenter clamping [12]

The clamping force can also be expressed from the balance of torques:

$$F_A \cdot l_A = F_s \cdot e + F_{\mu 1} \cdot \frac{D}{2} + F_{\mu 2} \cdot \frac{d}{2} = F_s (e + \mu_1 \cdot \frac{D}{2} + \mu_2 \cdot \frac{d}{2})$$

$$F_s = \frac{F_A \cdot l_A}{e + \mu_1 \frac{D}{2} + \mu_2 \frac{d}{2}}.$$

A 3-17. In addition to the so-called push eccentrics shown in (Figure 3-17), pull eccentrics (Figure 3-18) or eccentric shafts are sometimes used. To reduce wear, eccentrics are most often made of C15 steel, cemented and hardened to a hardness of 48-52 HRc.

Eccentrics can also be purchased ready-made, their working surface being mostly an Archimedes' spiral.

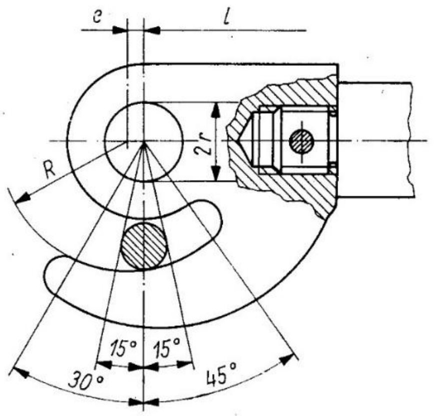


Figure 3-18. Pulling eccentric

3.2.4 CLAMPING IRONS

Clamping irons are simple and relatively inexpensive clamping devices, working on the principle of the single- and double-arm lift. The basic element is the clamping bar, or two-armed support in the narrower sense, which rests with one end on the top of the workpiece and the other on a support pin. The clamping force is created by a screw or eccentric clamp (Figure 3-19).

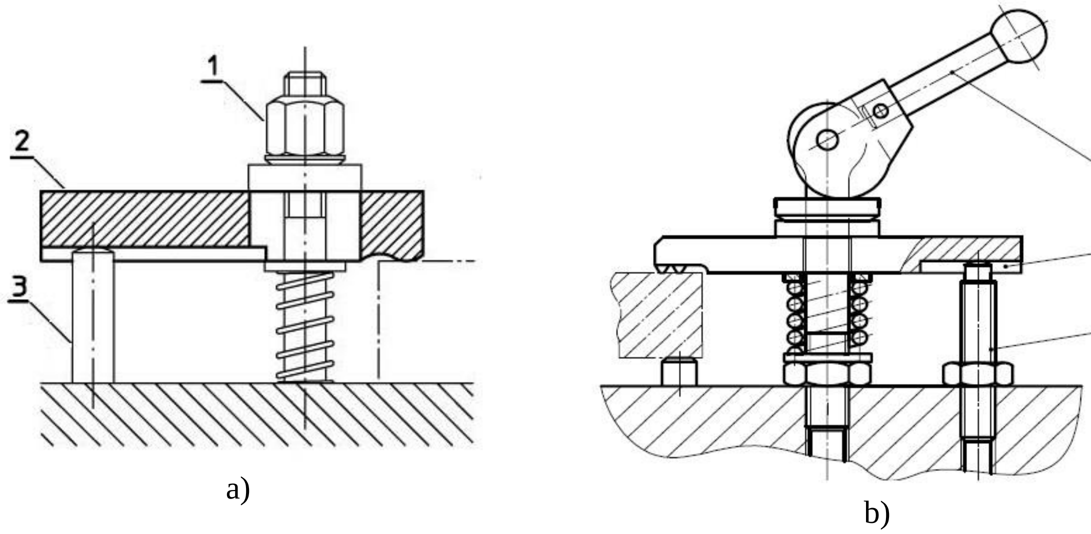
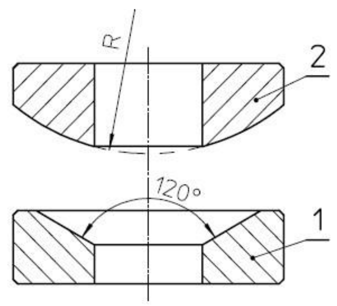


Figure 3-19. Clamping iron [12]

a) with screw clamping, b) with eccentric clamping

They come in a variety of standard designs, but their shape may differ from the standard. They can be made of structural steel (E 295, E 315) or heat treated steel (2C45). In hardened condition, they may damage the machined surface. The location of the iron clamp also varies as the workpiece is dispersed in size, so a pair of cup washers and lens washers should always be placed between the nut and the clamping iron (Figure 3-20).

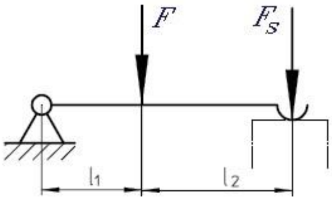
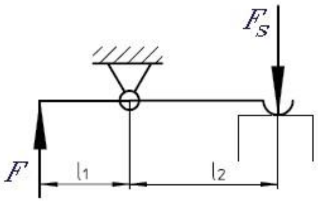
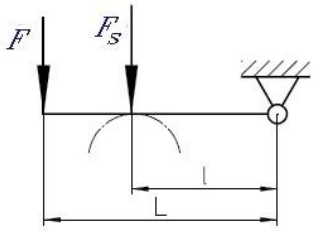


3-20. ábra. Pairs of cup and lens washers

1- cup washer, 2- len washer

Three typical arrangements are distinguished according to the location of the force application and the clamping force. The clamping force that can be achieved as a function of the force applied, the typical length dimensions of the jack and the type of arrangement are listed in Table 3-3.

Table 3-3. Determination of clamping force

Type of layout	Conceptual sketch	Clamping force
Force is applied between the support and the clamping point.		$F_s = F \cdot \frac{l_1}{l_1 + l_2}$
Force application at the end of the jack, support in the middle		$F_s = F \cdot \frac{l_1}{l_2}$
Force application at the end of the jack, clamping in the middle		$F_s = F \cdot \frac{L}{l}$

Figures 3-19, 3-21 and 3-22 each show an example of the principles listed. It should be mentioned that there is a fourth alternative, where the workpiece is clamped through a through hole (Figure 3-23), but in terms of clamping force this is classified as direct bolt clamping.

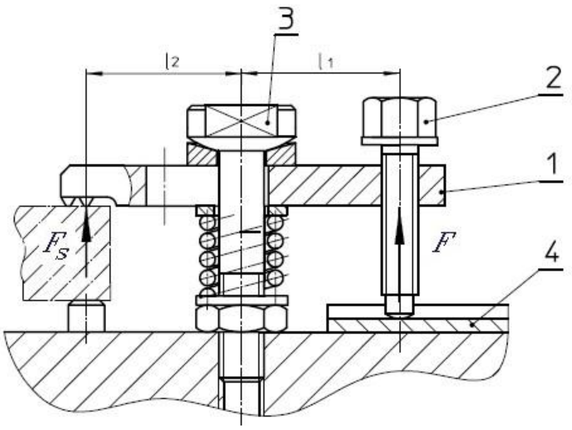


Figure 3-21. Iron clamp, force application at the end of the jack, support in the middle

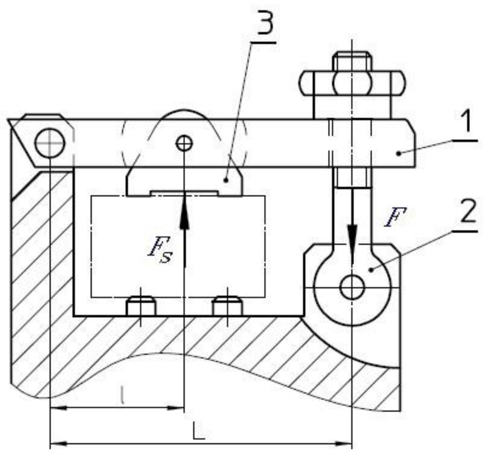


Figure 3-22. Iron clamp, force application at the end of the jack, clamping in the middle

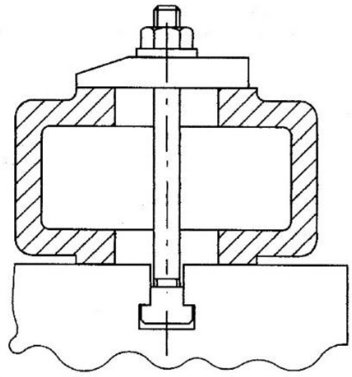


Figure 3-23. Clamping with fork clamp, through bore

3.2.5 USE OF AN ANGLE ADJUSTER FOR CLAMPING

INCLINED CLAMPING

Inclined clamping works on the principle of an angle adjuster. Its essential feature is that, due to friction, there is a downward component to the clamping force and so there is no risk of the workpiece lifting off the seats when side clamping (Figure 3-24).

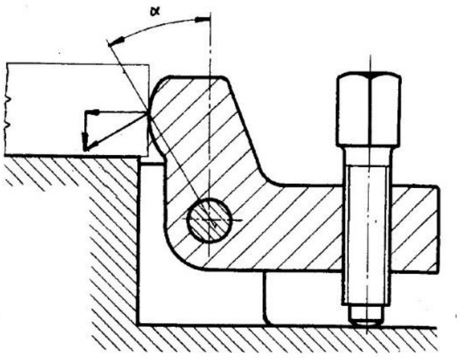


Figure 3-24. Inclined clamping

BIDIRECTIONAL CLAMPING

An angle adjuster may also be used where a clamping element is used to provide clamping in two perpendicular directions (Figure 3-25). It is most commonly used when the workpiece must be clamped simultaneously perpendicular to the guide and endwise locating planes.

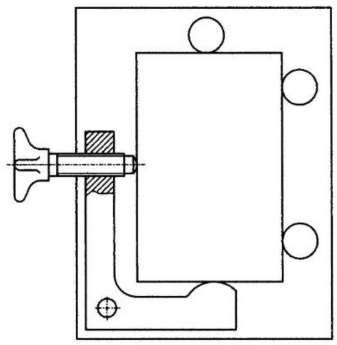


Figure 3-25. Bidirectional clamping

3.2.6 CENTRING CLAMPING

Centering clamping is the term used to describe solutions that perform centering and clamping with the same device element. Several solutions are used, all of them based on a flexible deformation of the clamping element.

EXPANSION MANDREL SLIT FROM ONE SIDE

Suitable for clamping workpieces with short bores. It has the disadvantage of expanding only at the outer edges (Figure 3-26). The tensioning cone may be self-locking, but this is not essential, as the threaded end that tightens the cone is always self-locking. For obvious reasons, the mandrel should only be deformed within the elastic limit and this determines the amount of bore tolerance that can be bridged:

$$T = \Delta D \leq 0{,}002 \cdot D$$

WHERE: T the tolerance range width

D is the bore diameter

It follows from this condition that the slit mandrel is suitable for centring holes of IT8, IT9 quality.

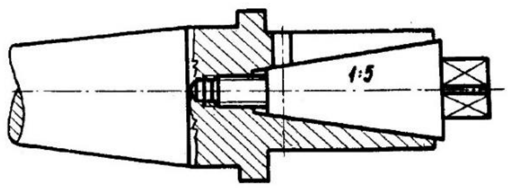


Figure 3-26. Expansion mandrel slit form one side

EXPANSION SLEEVE MANDREL SLIT ALTERNATELY FROM BOTH SIDES

Expansion sleeve mandrel remains cylindrical in the deformed state, so that centering and clamping are achieved over the entire length of the bore (Figure 3-27). It is well centred. Sleeve tensioning can be achieved with one taper (Figure 3-27) or two tapers (Figure 3-28). The size dispersion that can be bridged is larger than with single slit mandrels and this solution can be used for bores as small as IT13, IT14.

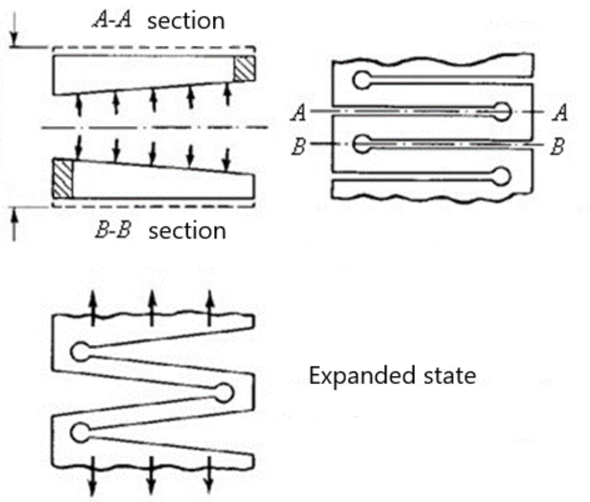


Figure 3-27. Deformation of sleeve slit from both sides [11]

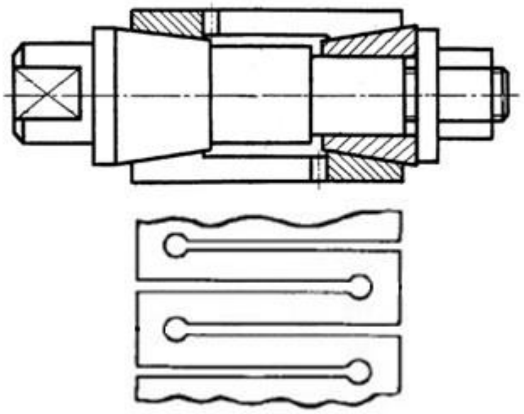


Figure 3-28. sleeve mandrel slit from both sides with biconical tensioning

CLAMPING SLEEVES (CARTRIDGES)

They are used to clamp external cylindrical surfaces for centring (Figure 3-29). The deformation of the clamping cartridges is similar to that of a single-sided slit mandrel, except that the deformation is produced by a tapered ring (Figure 3-30).

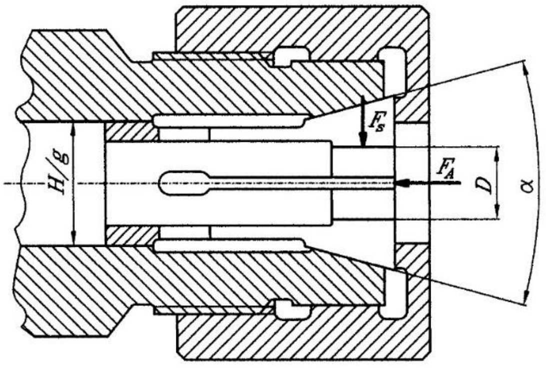


Figure 3-29. Clamping cartridge

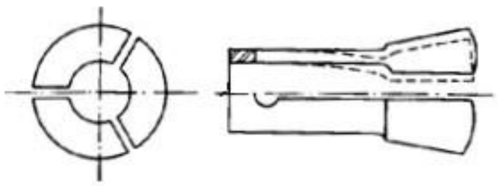


Figure 3-30. Deformation of clamping cartridge

Depending on the value of the taper angle, the cartridge may be self-locking, but in this case an appropriate release force must be applied to release it (Figure 3-31), and therefore this is rarely used, mainly for small devices.

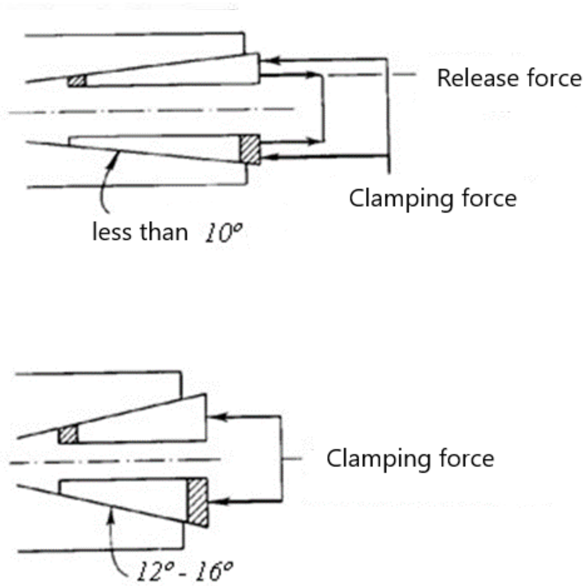


Figure 3-31. Self-locking and self-releasing tightening cartridge [11]

When clamping, the axial displacement of the cartridge is accompanied by a corresponding workpiece displacement. If this would cause a problem, either a bumper must be used or a solution must be adopted where the tapered sleeve moves instead of the cartridge (Figure 3-32).

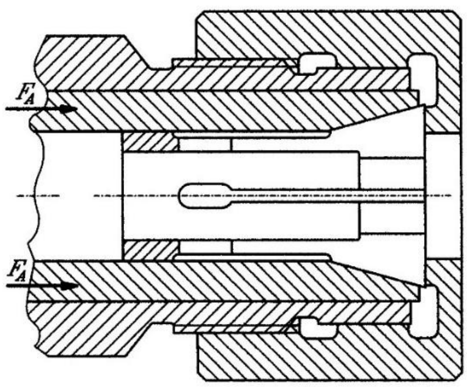


Figure 3-32. Clamping by displacement of the cartridge or tapered ring

The principle of clamping is based on wedge clamping, so the relationship between clamping force and activating force can be determined using the relationship obtained for wedge clamping (Figure 3-28):

$$F_A = F_s \cdot tg(\frac{\alpha}{2} + \rho_1).$$

WHERE: α the cone angle
ρ_1 is the friction half cone angle between the cartridge and the clamping ring.

If the displacement of the workpiece is hindered by an impactor, the friction between the workpiece and the cartridge must also be taken into account in the context of the clamping and activating forces:

$$F_A = F_s \cdot [\, tg(\frac{\alpha}{2} + \rho_1) + tg\rho_2 \,]$$

WHERE ρ2 is the friction half cone angle between the cartridge and the workpiece.
Cartridges are made of tool or spring steel and heat treated to a hardness of 62-65 HRc.

3.2.7 HYDROPLASTIC CLAMPING

The principle of the hydroplastic expansion mandrel is shown in Figure 3-33. A thin-walled sleeve (2) is fitted to the base body (1) with a relatively large overlap (H7/s6). The closed space between the base body and the sleeve (3) is filled with a hydroplastic material, which is subjected to a relatively high pressure (about 100 bar) by the piston (4). The hydroplastic material deforms (stretches) the centering sleeve of the device elastically due to its incompressibility. The piston can be moved by means of the screw (5). An important requirement is that no air bubbles remain in the hydroplastic material during filling, therefore the installation of the venting screw (6) is necessary. The hydroplastic mandrel is very accurately centred (2-3 µm) when well prepared. A hydraulic expansion bushing can be designed using a similar principle, which can also be used to capture external cylindrical surfaces. The thin-walled bushing material is spring steel with a hardness of 42-44 HRc. Oil, soft rubber or special plastics can be used as hydroplastic material. The manufacturing process is more demanding than that of mechanical structures. Its advantages can be summarised as follows:

_the clamping force is evenly distributed over the entire surface
_can be produced in any length,
_several different diameters can be centred at the same time,
_when well made, it centres very accurately.

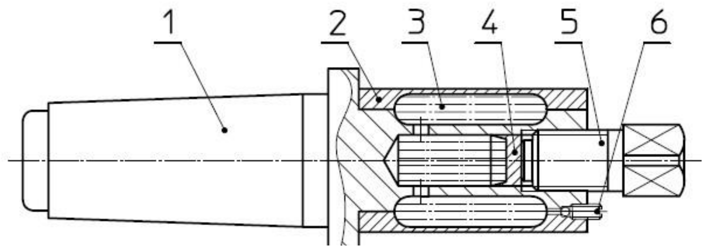


Figure 3-33. Hydroplastic mandrel [12]

1-base body, 2-sleeve, 3-hydroplastic, 4-piston, 5-clamping screw

The fact that the pressure is evenly distributed in all directions can be exploited in the design of multi-position (multi-workpiece) clamping devices. Figure 3-34 shows an example of the use of hydro-plastic clamping for a multi-position fixture.

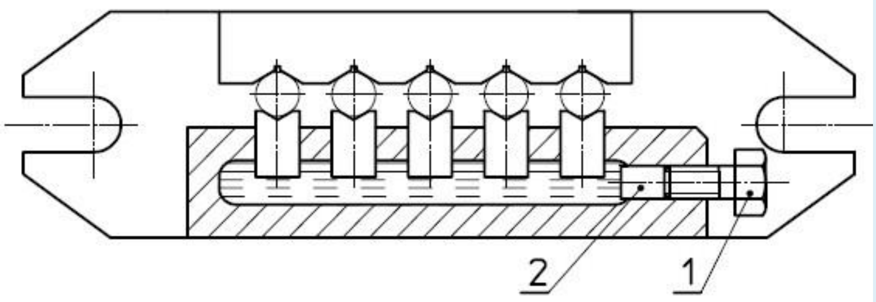


Figure 3-34. Multi-position hydro-plastic holder fixture

1- clamping screw, 2- piston

3.3 MACHINERY CLAMPING

The force-applying elements of machinery clamping devices are mechanically operated. Such devices are usually more expensive and offer the following advantages:

_the amount of clamping force is constant and adjustable
_the worker is spared
_time saving

Pneumatic clamping is the most common, but hydraulic, electromagnetic and vacuum clamping are also sometimes used.

3.3.1 PNEUMATIC CLAMPING

The clamping force is provided by a pneumatic working cylinder. The system of pneumatic elements required for its operation is illustrated in Figure 3-35.

The compressed air is usually produced centrally in a single production plant and from there is distributed to the users through appropriate pipes or connecting pipes, which can be considered as a source of compressed air (1). The connecting pipes are fitted with shut-off valves (2). An air preparation unit (power supply) (3) consisting of an air filter, a pressure regulator and an oiler shall be installed in front of each user. The installation of a non-return valve (4) prevents the workpiece from coming loose in the event of a pressure drop in the network for whatever reason. The movement of the piston (7) or piston rod (8) is controlled by the control valve (5) in such a way that the compressed air is guided to the appropriate connection of the cylinder (6).

The achievable clamping force on the piston rod:

$$F_s = p \cdot A$$

WHERE:

p air pressure

$A = \dfrac{D^2 \cdot \pi}{4}$ the surface area of the piston,

D cylinder diameter

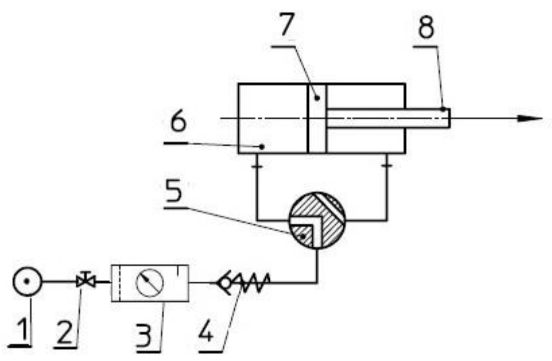


Figure 3-35 Typical elements of pneumatic systems

In pneumatic networks, the pressure is usually between 4 and 6 bars, exceptionally up to 10 bars. Pneumatic cylinders and other components are usually supplied by specialised companies. The task is to select the right cylinder from the manufacturers' catalogue. The piston surface area and cylinder diameter are determined on the basis of the required clamping force:

$$A = \frac{F_s}{p}, \qquad D = \sqrt{\frac{4 \cdot F_s}{p \cdot \pi}}.$$

Based on the diameter obtained by calculation, the first larger standard diameter from the catalogue is chosen. In addition to the diameter, the other parameter of the cylinder is the stroke length, which must be chosen according to the design of the device. Pneumatic working cylinders can be of the pedestal, flange or articulated type, depending on the way in which they are mounted (Figure 3-36).

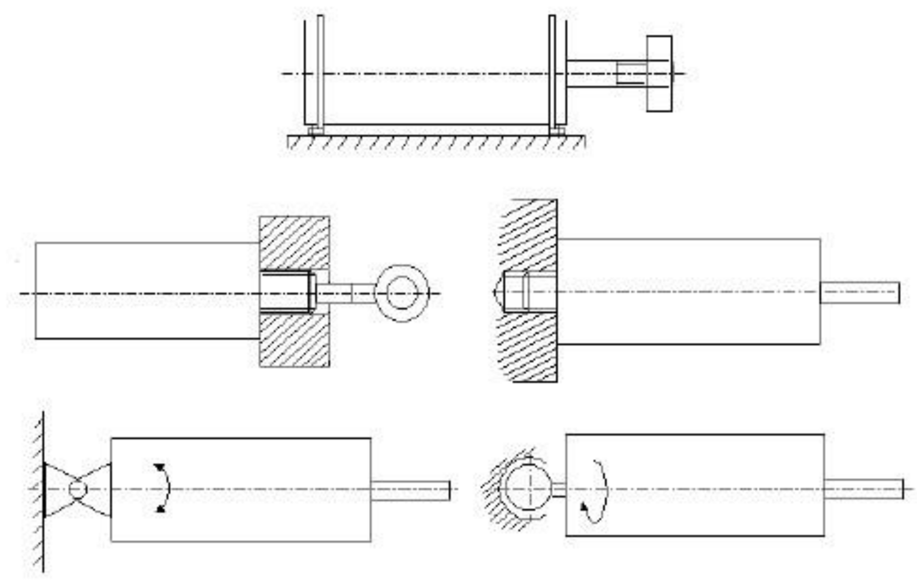


Figure 3-36. Installation methods for work cylinders

In addition to the work cylinders shown, specially designed clamping cylinders or clamping pads (Figure 3-37) can be used to apply the clamping force directly to the workpiece surface. The clamping pads has a large surface area and a short stroke (Figure 3-38). These structural characteristics are a consequence of the intended application, since clamping requires high force and short displacement.

Figure 3-37. Square and round clamping pads (Festo)

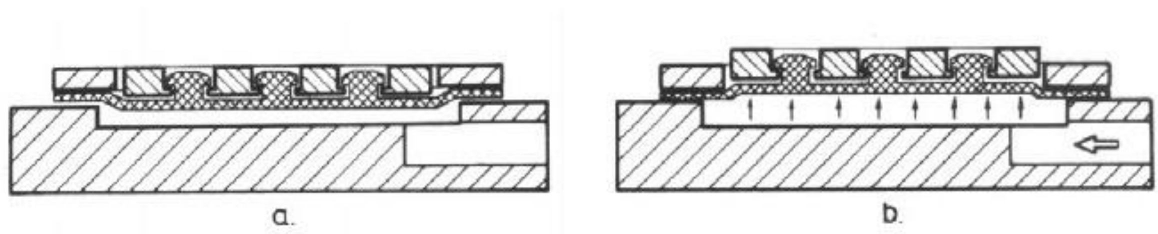


Figure 3-38. Operation of a clamping pad

(a) extended condition, (b) clamping condition

3.3.2 HYDRAULIC CLAMPING

Hydraulic clamping is relatively rarely used for grippers. It is justified in cases where high clamping forces are required with small cylinder sizes. In hydraulic cylinders, for example, the oil pressure is 60-300 bar and therefore the cylinder diameter is understandably considerably smaller than in pneumatic clamping. The clamping device is powered by a separate hydraulic power supply (aggregate) and this makes such solutions very expensive.

3.3.3 PNEUMO-HYDRAULIC CLAMPING

Pneumo-hydraulic clamping combines the advantages of pneumatic and hydraulic clamping. It is used to generate high clamping forces (Fs = 30-150 kN). The pneumo-hydraulic booster converts the air pressure of 4-6 bars into an oil pressure several times higher by means of a differential piston (Figure 3-39).

Force acting on the piston of the pneumatic cylinder:

$$F = \frac{D^2 \cdot \pi}{4} \cdot p \,,$$

The pressure created in the hydraulic line:

$$p_1 = \frac{F}{\frac{d^2 \cdot \pi}{4}} = \left(\frac{D}{d}\right)^2 \cdot p \,,$$

the clamping force:

$$F_s = \frac{d_1^2 \cdot \pi}{4} \cdot p_1 = \left(\frac{D}{d}\right)^2 \cdot \frac{d_1^2 \cdot \pi}{4} \cdot p \,.$$

WHERE: *p* air pressure,
D is the diameter of the pneumatic cylinder,
d is the small diameter of the differential piston,
d_1 is the diameter of the hydraulic clamping cylinder,
p_1 oil pressure.

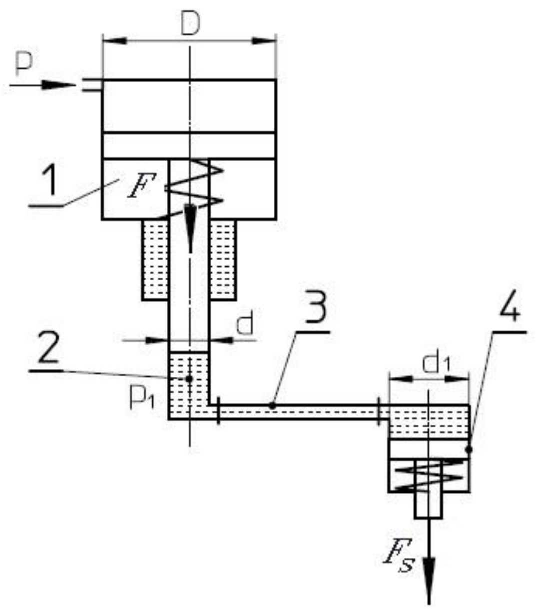


Figure 3-39. Pneumo-hydraulic pressure booster

4. DIVIDER FIXTURES

It is often necessary to change the location of a clamped workpiece in relation to the tool without holding the workpiece. The different locations are achieved by means of a dividing device. With regard to the direction of movement, a distinction is made between circular and longitudinal dividers. The latter are only rarely used, so we will briefly discuss only the circular strokers here.

The main parts of a circular divider are as follows (Figure 4-1):

_the dividing shaft (1), which rotates together with the workpiece clamping part,
_dividing plate (2), most often fixed to the shaft,
_latch (3).

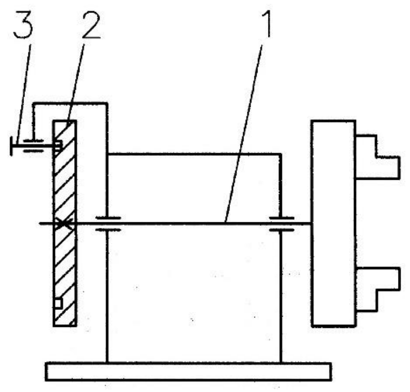


Figure 4-1. Main parts of a circular divider

The dividing plate is usually made with bores or grooves corresponding to the number of divisions (Figure 4-2). It is important that the bores (slots) are as far away from the axis of rotation as possible, as this will reduce the division error due to clearance between the slot and the latch.

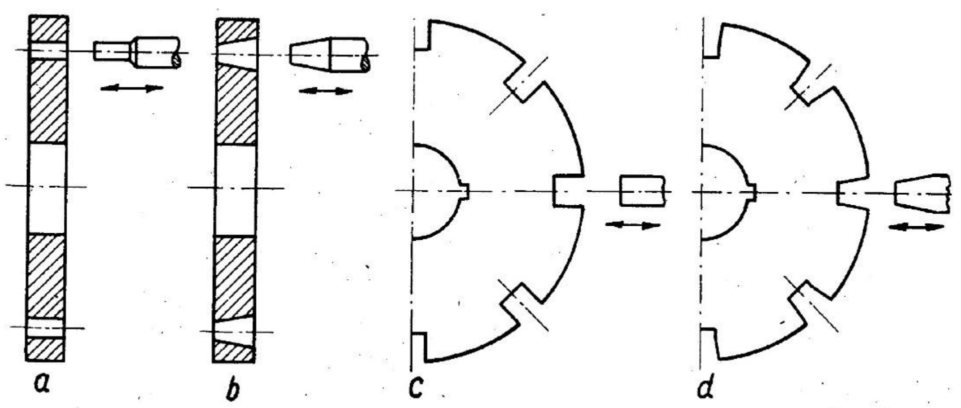


Figure 4-2. Dividing plate and latch designs [9]

a) cylindrical, b) conical, c) slotted, d) wedge

THE FOLLOWING SOLUTIONS CAN BE USED FOR THE LATCH DESIGN:

_cylindrical pin (simple to manufacture, it pushes any chips that may have fallen into the slot out of the slot, there is some play between the slot and the latch),
_tapered pin (provides a clearance-free fit, with the possibility of shavings being trapped between the slot and the latch)
_slotted (rare) and wedge (same characteristics as described for cylindrical and tapered pins),
_in the case of a handle latch, the latch does not turn in a straight line, but around a pin (Figure 4-3),
_ball latches are simple in design, release with little force and are often used as an auxiliary device to facilitate other latching operations (Figure 4-4).

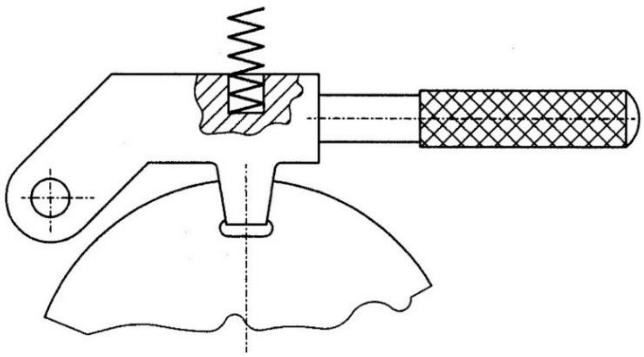


Figure 4-3. Handle latch

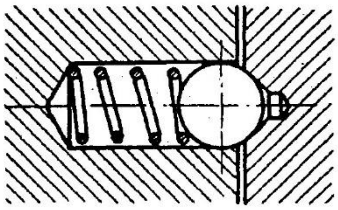


Figure 4-4. Ball latch

If there is some clearance between the latch and the slot, this will lead to vibrations during machining, so the dividing plate must be fixed after dividing. In most cases, this can be achieved by screw or eccentric clamping. Depending on the clamping direction relative to the dividing plate, the clamping can be axial or radial.

Longitudinal dividers can be used for machining bores or grooves spaced apart by a certain distance. The moving part of the device can be moved in a guided manner and the locking is done in the same way as already described.

5. TOOL SETTING AND TOOL GUIDING ELEMENTS

5.1 TOOL SETTING ELEMENTS

The location of the workpiece in the machine is determined by the seats, so in essence, when setting up the machine, the tool edge must also be determined in relation to the seats. In custom manufacturing, tool setting can be done by trial fitting or by pre-drawing. In batch production, however, it is advisable to place tool setting elements on the machine. Depending on the number of dimensions or directions of movement that can be set, the tool setting elements can be either (1) unidirectional setting elements or (2) bidirectional, so-called corner setting elements (Figure 5-1). The tool setting elements are made of tool steel, hardness 57-60 HRc after hardening and tempering. They are usually machined to final size by surface grinding after installation. During tool setting, a washer (gap gauge) is placed on the setting element to match the machining dimension. After adjustment, this is removed to allow the tool to move freely. It should be noted that on modern CNC machines, tool setting and, of course, tool setting elements are not necessary.

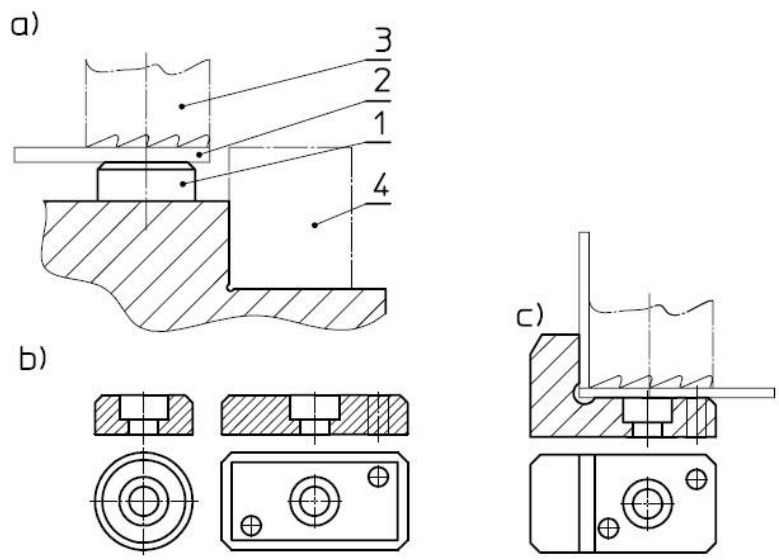


Figure 5-1. Tool setting elements [12]

a) Tool setting: 1 - tool setting element, 2 - gap gauge, 3 - milling cutter, 4 - workpiece;
b) design of unidirectional setting elements
c) corner adjustment element

5.2 TOOL GUIDING ELEMENTS

Tool guides are most commonly used for machining on drilling machines. It should be stressed that such elements are only used on conventional machine tools. Drilling bushes are used to ensure the locating of the bores and the orientation of the drill axes. They are made of tool steel or case-hardened steel (C 105 U, C10), hardened to a hardness of 60-65 HRc and finished by grinding. The shape and dimensions of the drill bushes are laid down in standards, but special drill bushes can also be made to suit the task. Drill bushes are subdivided according to their shape as follows:

_ fixed drill bushings (Figure 5-2)
- cylindrical
- with flange
- special

_interchangeable bushings (Figure 5-4).

Fixed bushings are used when the bore machining consists only of drilling or when the bushing can be turned or removed together with the drill bit during post-drilling machining (reaming, reaming).

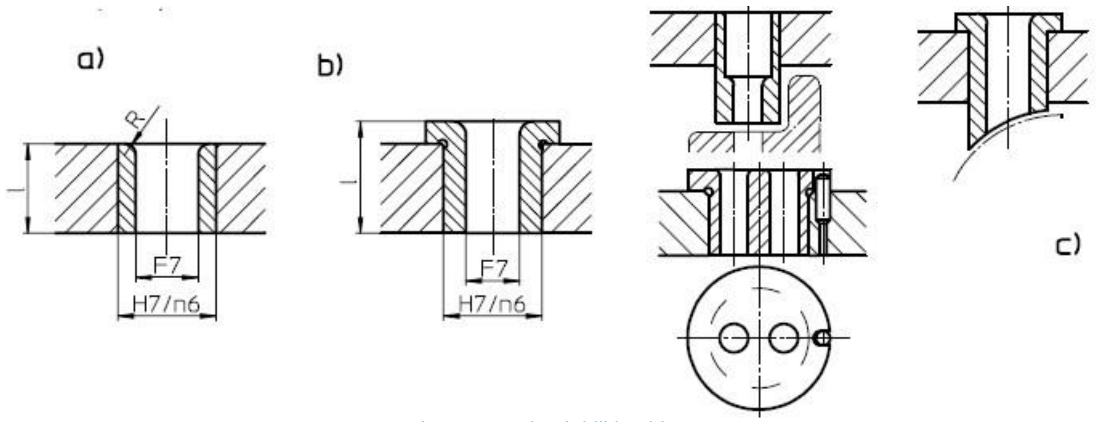


Figure 5-2. Fixed drill bushings

(a) cylindrical, (b) flanged, (c) special drill bushes

The diameter of the auger is made with a tolerance of h8. Because of its slenderness, groove-weakened cross-section and edge design, it tends to go off centre and drill bores larger than its diameter. The expected variation in bore diameter for unguided drilling is classified in accuracy class IT13. By using a drill bushing, a bore diameter accuracy of IT 10 can be achieved. The diameter error is made up of the following components:

$$\delta_d = \delta_1 + \delta_2 + \delta_3 + \delta_4$$

WHERE:

δ_1 –diameter tolerance of auger (h8),
δ_2 – bushing bore tolerance (F7),
δ_3 – clearance between drill and bushing,
δ_4 – allowable wear of the bushing (8i, i- is the tolerance unit).

The locational accuracy of the bore depends on the accuracy of the bushing location (δhp) and the locational error due

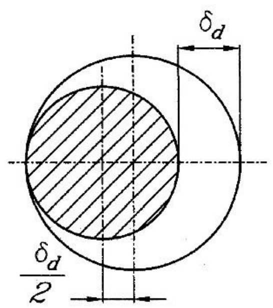


Figure 5-3. Location error due to diameter dispersion

to the bore diameter variation during tool manufacturing (Figure 5-3):

$$\delta_h = \delta_{hp} + \frac{\delta_d}{2}$$

Interchangeable drill bushings are used when the bore is to be machined with several guided tools of different diameters. The interchangeable bushing should always be mounted in a hardened sub-bushing. The locational accuracy of the drilled bore is lower than when using fixed bushings.

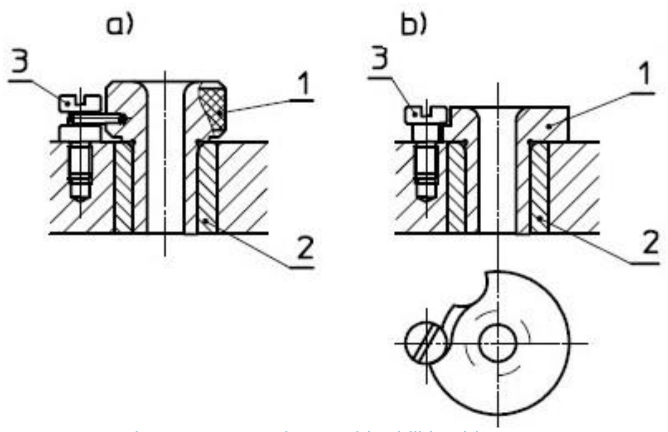


Figure 5-4. Interchangeable drill bushings

When designing drilling fixtures, it is a good idea to keep the following practical guidelines in mind:

_The length of the drill bushing should be 1.5 to 2 times the drill diameter.

_The distance between the workpiece surface and the bushing depends on the workpiece material and the accuracy requirements of the bore. Too large a gap will compromise accuracy, while too small a gap will cause the resulting chips to lift the drill bit. In practice, for short chipping materials, the gap can be half the bore diameter, while for long chipping tough materials, a gap of 1 to 1,5 bore diameters is recommended. When drilling high-precision bores, the bushing can be laid directly on the workpiece surface.

_When drilling on a non-uniform surface, direct contact between the drill bushing and the bore carrier surface shall be ensured.

6. FIXTURE BODIES AND FIXTURE PLACING ELEMENTS

6.1 FIXTURE BODIES

The function of the fixture bodies is to hold the individual components together and ensure their smooth interaction. Rigidity, economic manufacturability and easy, quick and safe handling are important aspects in the design of the body. Particular attention should be paid to accident prevention and to ensuring the drainage of chips and coolant. From the manufacturing point of view, three types of body are distinguished (Figure 6-1): (1) cast, (2) welded and (3) assembled.

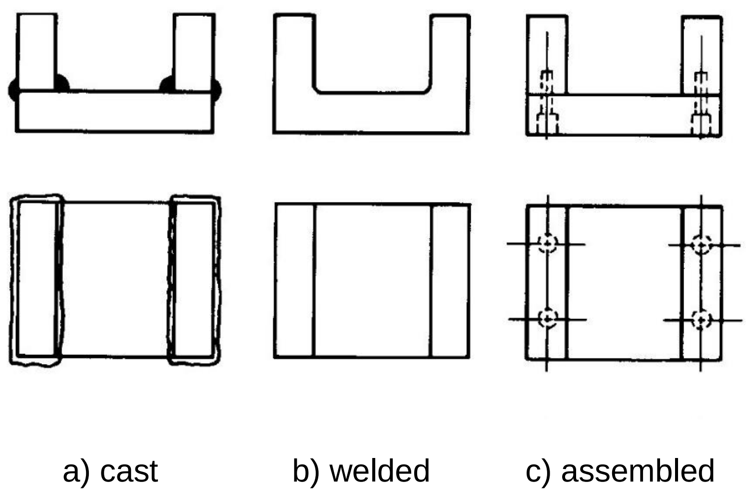


Figure 6-1. Types of fixture bodies [11]

CAST BODIES

Cast bodies are usually made of cast iron, aluminium or epoxy resin. These bodies are mainly used for devices produced in series. Their advantages include high stability and vibration damping, good material utilisation and relatively low machining costs. It should be noted, however, that moulded bodies are generally expensive because a separate mould has to be made for each body. Another disadvantage is the relatively long time between design and production of the device.

WELDED BODIES

Welded bodies are made of weldable steel or other weldable materials (aluminium, magnesium, etc.). These bodies are relatively simple to manufacture and have the shortest lead times. Welded bodies have high strength and rigidity and can be relatively easily modified if necessary. A disadvantage is that after welding, heat treatment and subsequent machining of the functional surfaces is required.

MOUNTED BODIES

Mounted bodies can be made of different materials. The most commonly used materials for body designs are steel, aluminium, cast iron, wood and epoxy resins. This is the most universal and commonly used type of body. They are relatively inexpensive to manufacture, are easy to modify and require minimal rework after installation.

6.2 THE RELATIONSHIP BETWEEN THE FIXTURE AND THE MACHINE TOOL

The design of the device is determined by the specific nature of the workpiece and the machining task. As a result, the location of the workpiece in the tool is clearly defined. On the other hand, the fixture must be adapted to the machine tool's mounting surface (machine table or main spindle lathes), i.e. it must also be possible to locate and clamp the fixture. The working surfaces of machine tables and the mating surfaces of main spindles are standardised, so this task is relatively simple. Of course, when designing the equipment, it is necessary to know the working area of the specific machine and the design and dimensions of the machine table mounting surfaces. Depending on the design of the machine table, the following solutions can be used for locating the machine:

_the flat surface of the fixture body is laid on the flat surface of the table (for drilling machines),
_the flat surface of the table is covered by the fixture feet incorporated in the fixture body (for small drills),
_with a flat surface and using orientation stubs (Figure 6-2),
_with a flat surface and guide and endwise locating bars (Figure 1-3),
_with flat surface and centring bore,
_with tapered bore (lathes).

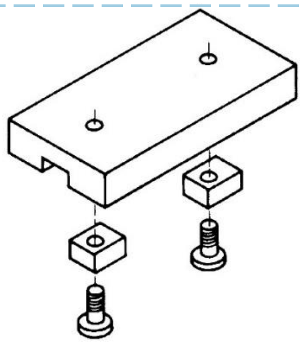


Figure 6-2. Locating of the device with orientation stubs in T-slots

The following solutions can be used to clamp the fixture to the machine table (Figure 6-3):

_by hand (for devices for drilling small diameters),
_ using screws,
_clamp irons,
_magnets.

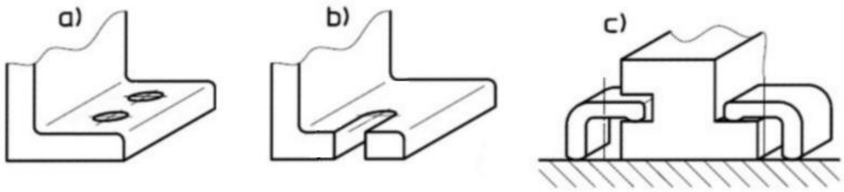
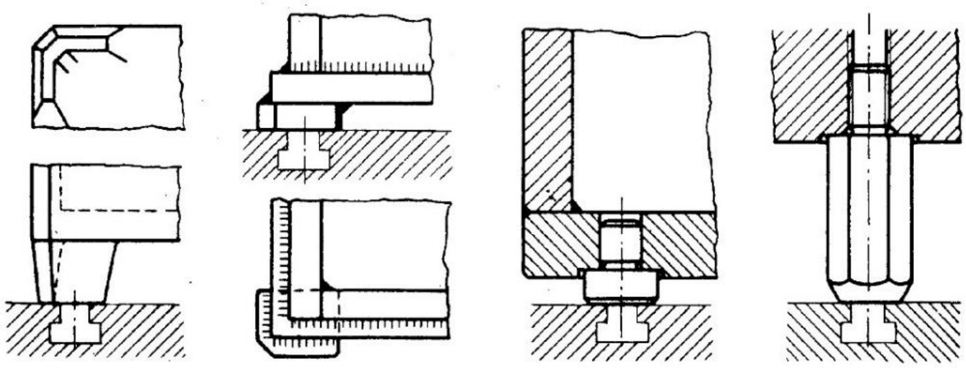


Figure 6-3. Design of surfaces suitable for clamping the device

(a) bores, (b) fixture lugs, (c) grooves and stepped surfaces

FIXTURE FEET

Attachment feet are generally used for small drilling machines that can be moved manually on the machine table. The mounting of the feet ensures the stability of the fixture and reduces the need to keep the machine table clean. An important requirement is that the size of the feet must be such that the unit can be moved over the T-slots without obstruction. Common solutions for the design of the legs are shown in Figure 6-4.



a) b) c) d)

Figure 6-4. Equipment feet

a) cast, b) welded, c) pressed, d) bolted

ORIENTING STUBS

The locating (guiding) of fixtures on T-slot machine tables can be done by means of orienting stubs. Usually, the orienting stub is mounted by means of a screw fixing in the grooves formed in the machine's plane locating surface (Figure 6-5). There are also solutions where only a bore is made in the plane locating surface of the device, which fits into a free orienting stub inserted in the T-slot when the device is mounted (Figure 6-6).

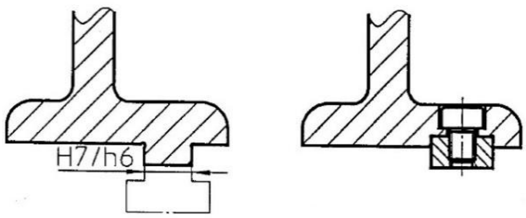


Figure 6-5. Integrated and fixed

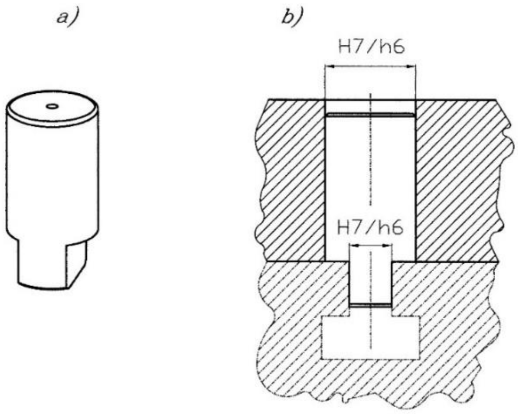
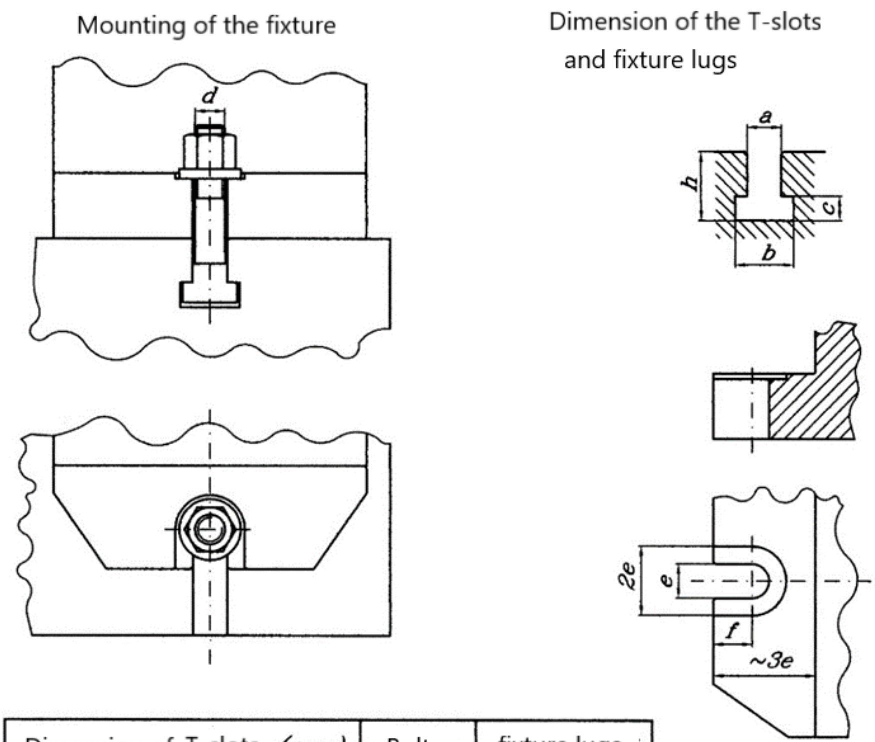


Figure 6-6. Axonometric view and installation of a free orienting stub

FIXTURE LUGS

Quick mounting of the fixture can be achieved by using hammerhead screws in the T-slots and fixture lugs on the fixture body (base plate). The dimensions of the lugs shall be determined according to the size of the clamping bolt and the T-bar (Figure 6-7).



Dimension of T-slots *(mm)*				Bolt	fixture lugs	
a^{H7}	b	c	h	d	e	f
8	15	7	16–18	M6	8	10
10	18	8	18–21	M8	10	14
12	21	9	20–23	M10	12	18
14	24	10	25–29	M12	14	21
18	30	12	32–37	M16	18	25
22	38	16	40–46	M20	22	30

Figure 6-7. Design and typical dimensions of the fixture lugs

HANDLING OF HEAVY FIXTURES

Heavy fixtures shall be fitted with a ring bolt to which the lifting device may be attached Figure 6-8.

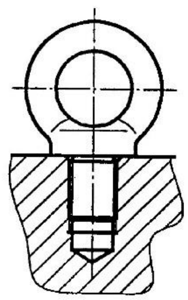


Figure 6-8. Installation of ring bolt

7. THE FIXTURE DESIGN PROCESS AND THE STRUCTURE OF THE DEVICES

7.1 STAGES OF THE FIXTURE DESIGN PROCESS

The design process for clamping fixtures can be divided into typical stages to ensure the success of novice designers. The holding fixture should always be designed for a specific operation in the manufacturing process. The final aim of the design is to produce the assembly drawing of the fixture - and the shop drawings for non-standard components. To accomplish this task, of course, a whole range of input information is required, which is drawn from the results of the manufacturing process design. The following information is usually already known prior to the design of the fixture:

_drawing of the prefabrication,
_the division of the manufacturing process into operations and the delimitation of the content of the operations,
_the sequence of operations,
_the machine tool for each operation,
_the workpiece holding concept for each operation (positioning of the part in the machine's work area, base surfaces, type of plane locating and side locating, type of clamping and clamping surfaces).

7.1.1 DESIGN STAGES FOR DRILLING FIXTURES

The design stages are illustrated using the example of a drilling machine, since all the typical components are present. For the sake of clarity, details of the fixture drawing are not shown in the relevant figures.

The following workflow is recommended for the design of drilling fixtures [11]:

1. First step is to analyse the workpiece and identify the base surfaces. The location of the workpiece in the machine's work area is usually already defined by the operation sequence plan.

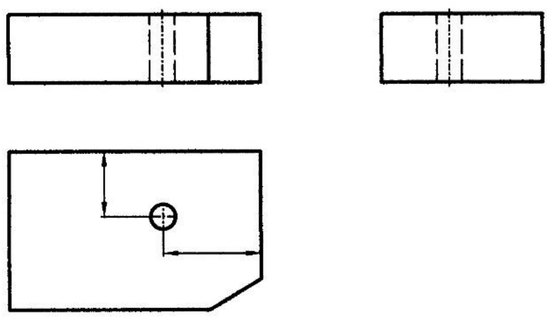


Figure 7-1. Outline of the workpiece

2. First draw the workpiece in three views. It is advisable to draw this with a thin line or a "two-point line" line type can be used. It is also a good solution to draw the workpiece in a selected colour (Figure 7-1).

3. The locating seats are drawn on the selected base surfaces of the workpiece in all three projections. Determine the plane locating first, followed by the side locating (lead and endwise locating) (Figure 7-2). The rough (unmachined) surface is required to be laid on three-point tap seats, while machined shaped surfaces may be laid on flat seats.

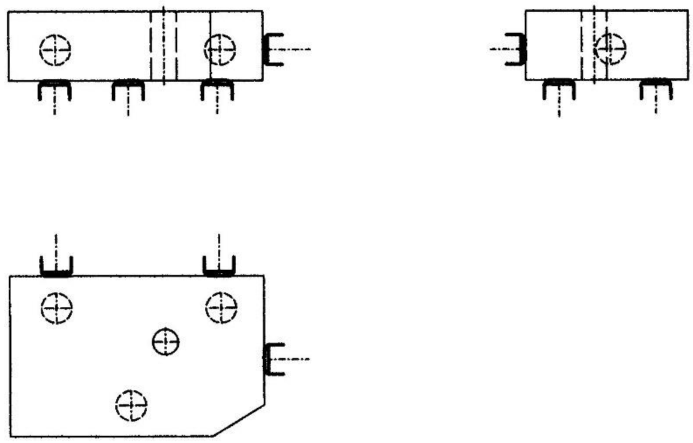


Figure 7-2. Drawing of locaing elements

4. After the seats have been drawn, the body of the fixture can be outlined, incorporating all the elements of the fixture (Figure 7-3). Care must be taken to avoid obstructions to the drainage of chips and coolant. Check that the location of the workpiece is not over-defined. Insertion and removal of the workpiece must be unobstructed. Only after the locating has been correctly resolved can the clamping method be determined.

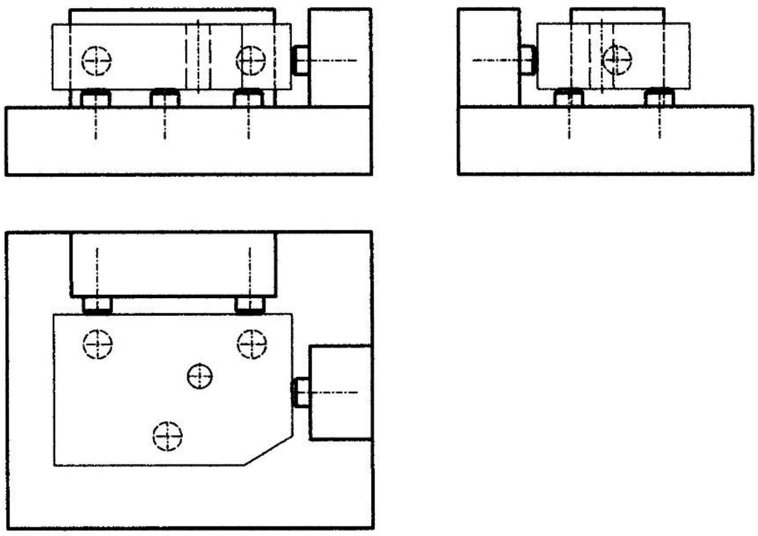


Figure 7-3. Schematic of the locating elements and body

5. Drawing of the clamping elements (Figure 7-4). When designing the clamping, it should be kept in mind that the clamping time directly affects the manufacturing cost. Therefore, a solution must be found that allows the clamping to be carried out in the shortest possible time. It is necessary to check that the clamping elements and the already drawn seats do not interfere with each other.

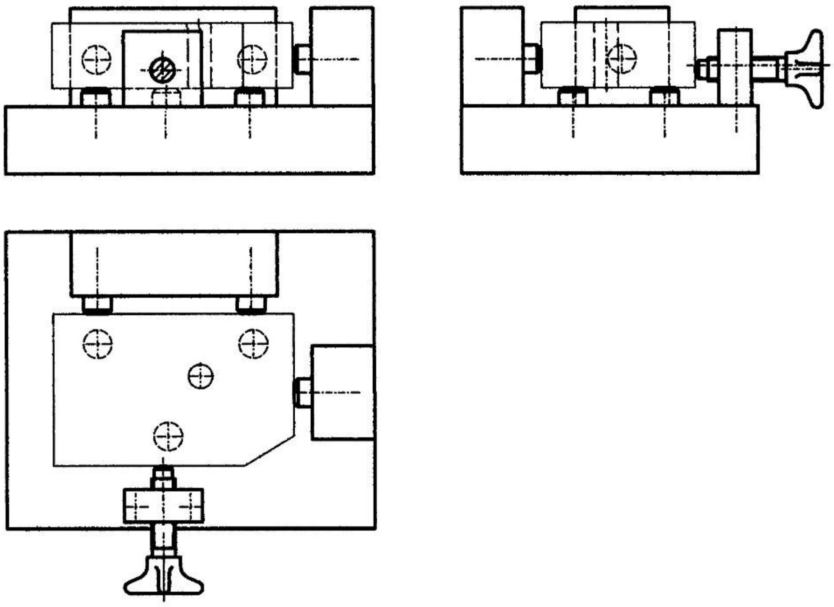


Figure 7-4. Drawing of clamping elements

6. After the clamping elements have been drawn, the bushings can be positioned on the corresponding projections of the drawing (Figure 7-5).

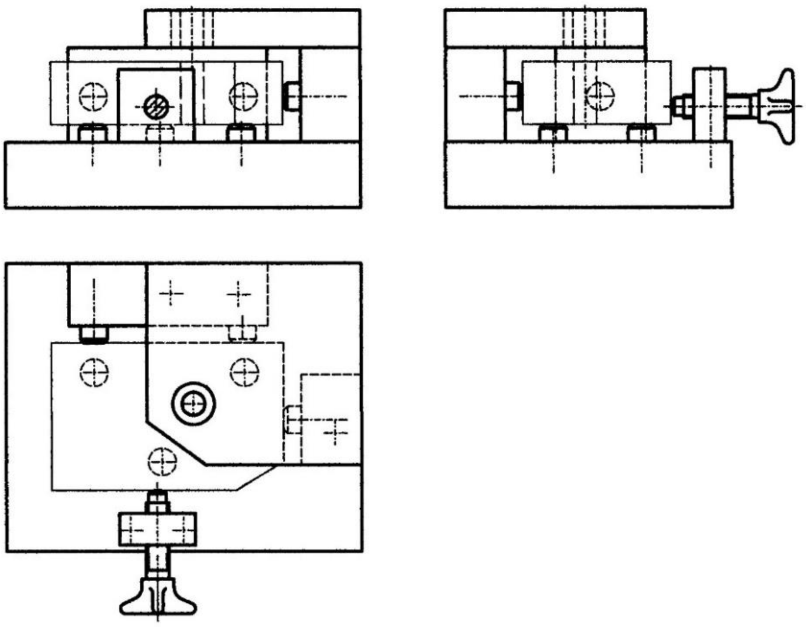


Figure 7-5. Drawing the drill plate and bushings

The schematic diagram of the fixture is now complete. What remains to be done is the design of the interfaces between the body and the machine tool table (or main spindle lathes). For T-slotted machine tables, orientation blocks and clamping lugs must be fitted. In the case of drills, where the bore diameter is less than 8 mm, the drill can normally be held by hand and it is not necessary to secure the drill to the machine table, only to provide a plane locating. For small drilling fixtures, fixture feet are often used as a plane locating surface.

7.1.2 DESIGN STAGES FOR MILLING FIXTURES

The design sequence for milling fixtures is similar to that for drills, except that drill bushings are not required. For clamping, eccentric clamping is not recommended; the milling attachment must always be fixed to the machine table.

The relative location of the machine table and the workpiece plane locating surface may dictate the design of the fixture:

_horizontal (flat), when the plane locating surface is parallel to the work surface of the machine table (Figure 7-6),
_vertical, when the plane locating surface is perpendicular to the work surface of the machine table (Figure 7-7), and
_inclined, when the base surface and the surface to be machined form an arbitrary angle (Figure 7-8).

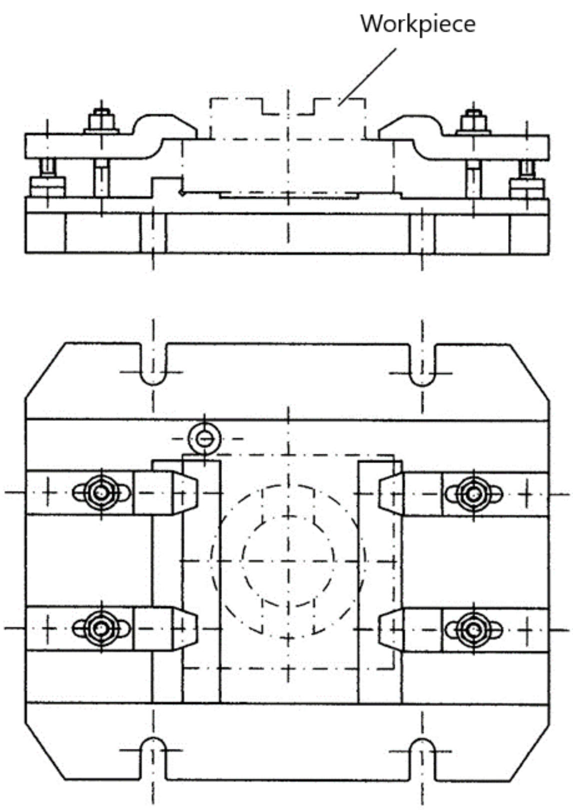


Figure 7-6. Horizontal (flat) fixture

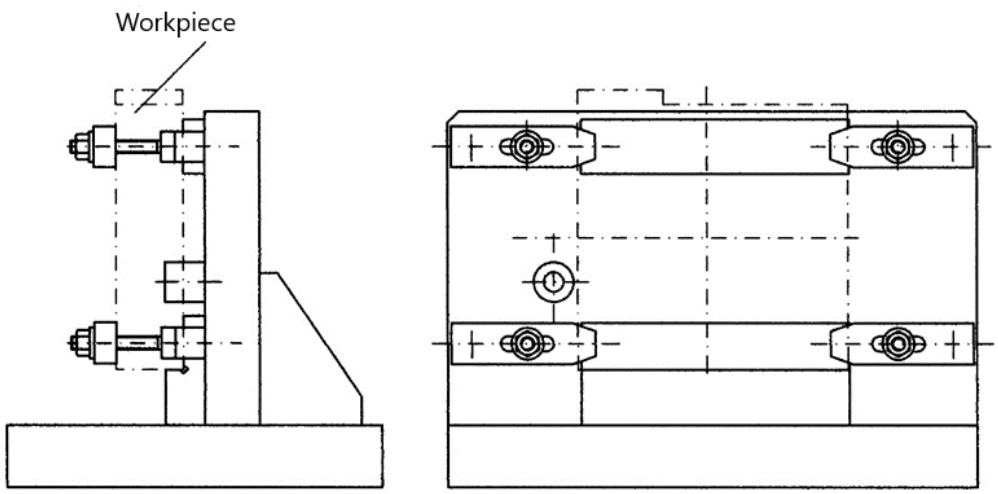


Figure 7-7. Vertical fixture

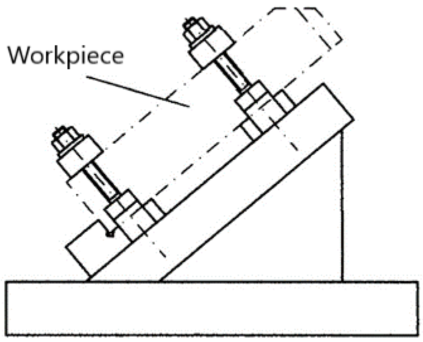


Figure 7-8. Inclined fixture

7.2 THE CONSTRUCTION OF THE FIXTURES

The construction of special holding fixtures can be very diverse due to the variety of workpieces, but certain similarities can be identified based on the function of the fixture and the sub-tasks (plane locating, side positioning, clamping). Three concepts or principles of construction can be distinguished in the construction of the fixtures:

_individual or special fixtures
_group fixtures
_fixtures that can be assembled from components

Individual or specialised fixture is only capable of holding a single workpiece and is therefore the most suitable solution for a given task, but also the most costly. The lead time from design to production is relatively long.

Group fixtures are similar to individual fixtures, but with some modification (adjustment or replacement of certain components) they can accommodate several similar parts. This can reduce the cost of the fixture, but it should be borne in mind that, in the event of market take-up of products, the group fixture may represent a bottleneck ("narrow band").

Assembly appliances are based on the building-block principle and represent a modern way of building appliances. A brief overview is given in the next chapter.

7.2.1 MODULAR COMPONENT FIXTURES (MCF)

Modular units are designed by breaking down the receptacles into their components and arranging them in a suitable order. The basic system of elements is a set of non-identical elements. By multiplying some elements of the basic system, extended systems of elements or modular component assemblies can be formed (Figure 7-9) [2].

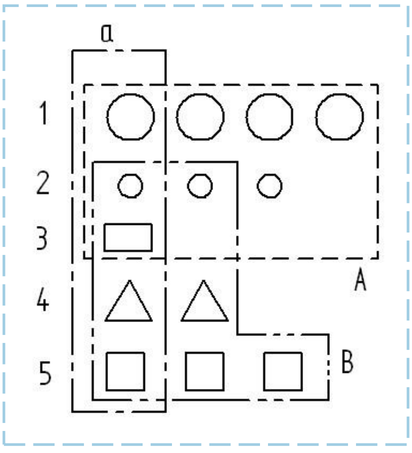


Figure 7-9. Design of modular component assemblies [2]

a -basic system
1...5 - individual elements of the basic system
A, B - extended element systems

The elements of the basic system are designed in such a way as to allow inter-assembly and thus the construction of a holding fixture adapted to the specific task. According to the method of attachment used to assemble the elements, they can be of the type of the MCF system (Figure 7-10):

_T-slot systems,
_drilled systems.

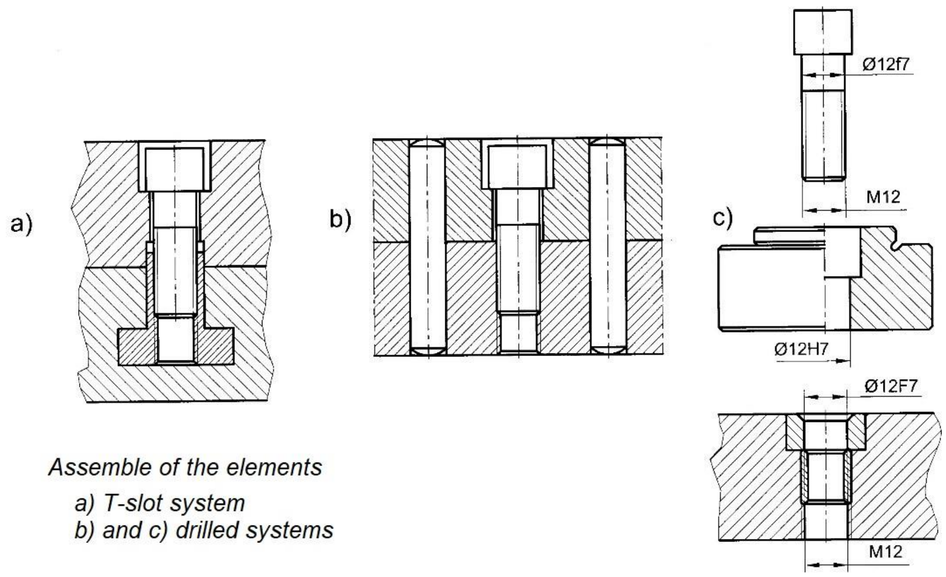


Figure 7-10. Fixing the modular elements

The elements of the basic system can be divided into three main groups:

_functional elements
_basic elements
_adaptive elements (extensions)

Of course, this does not include the various fasteners (bolts, studs, fitting screws, etc.) Most of the MCF systems are "open" or can be extended with special user elements if absolutely necessary (see Figures 7-15).

FUNCTIONAL ELEMENTS

Functional elements are those elements that directly perform a clamping function (plane locating, guiding, endwise locating, clamping) and are in direct contact with the corresponding surfaces of the workpiece. Figure 7-11 illustrates some of the functional elements of the fixture.

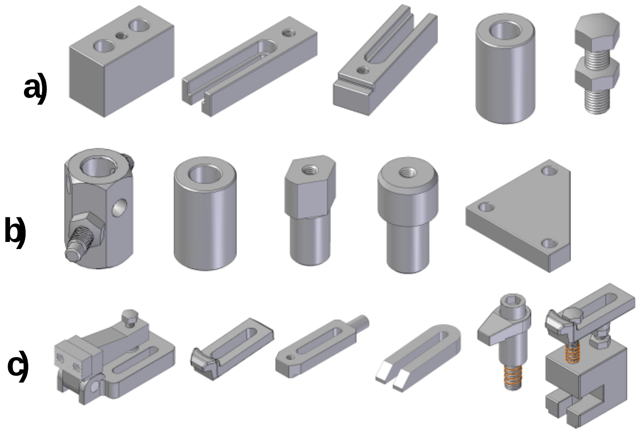


Figure 7-11. Some functional elements (Kipp)

a) Plane locating seats, b) Guiding and endwise locating seats, c) Clamping elements

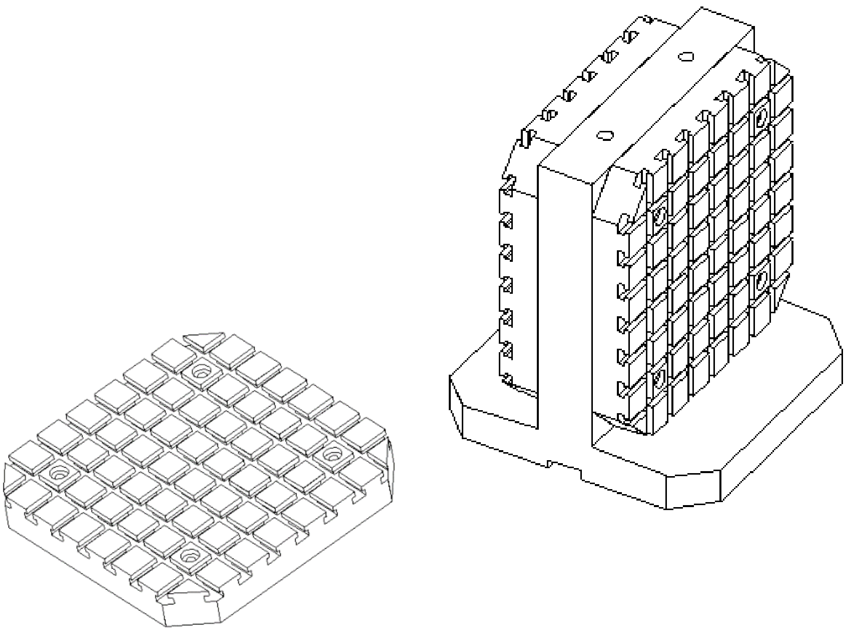


Figure 7-12. T-hook basic elements

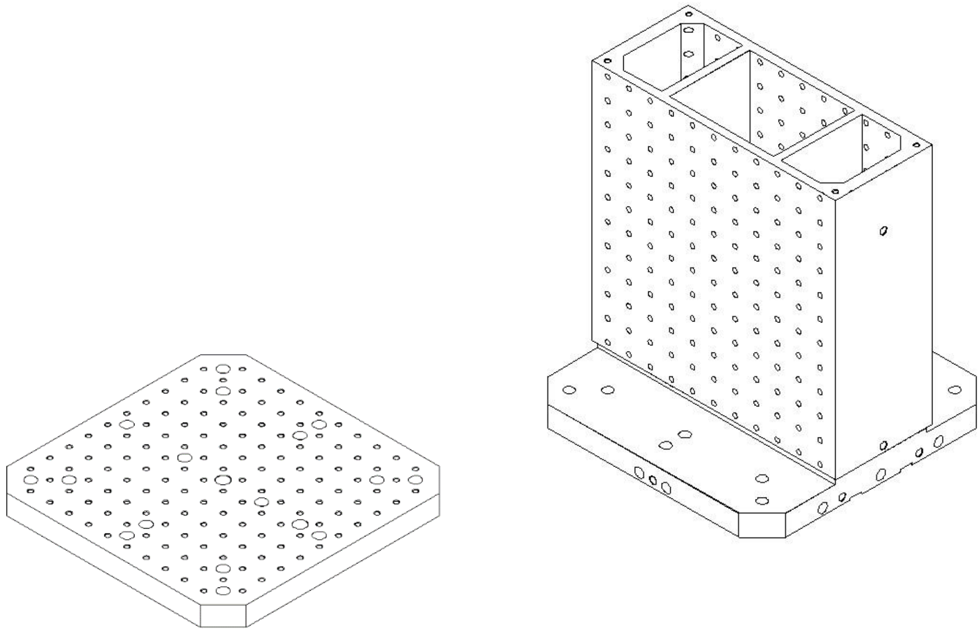


Figure 7-13. Boring base elements

BASIC ELEMENTS

The basic elements establish the connection with the machine table and are the basis for the other elements of the fixture (Figures 7-12 , and 7-13).

ADAPTING ELEMENTS (EXTENSIONS)

The adapting elements do not directly perform any part of the clamping task, but are integrated between the functional elements and the base element as required, thus ensuring the flexibility and adaptability of the MCF systems to different workpiece configurations (Figure 7-14).

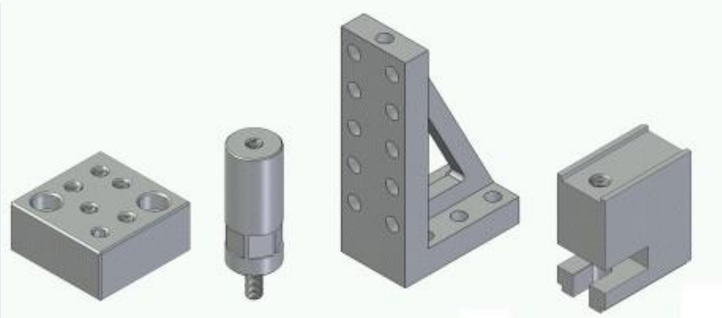


Figure 7-14. Adaptive elements (Kipp)

In some cases, the set of functional elements of the MCF may need to be extended with a user-made "adaptor plate" or other device element (Figure 7-15), which is appropriate for the workpiece. Such "raw" adaptor plates are also offered by companies manufacturing MCF systems (e.g. Heinrich Kipp Werk). They are made of heat treated steel, with ground flat surfaces and bores for assembly, and the user only has to work in the corresponding cut-outs or bores for the clamping screws.

Figure 7-16 shows a clamping fixture constructed from modular fixture components.

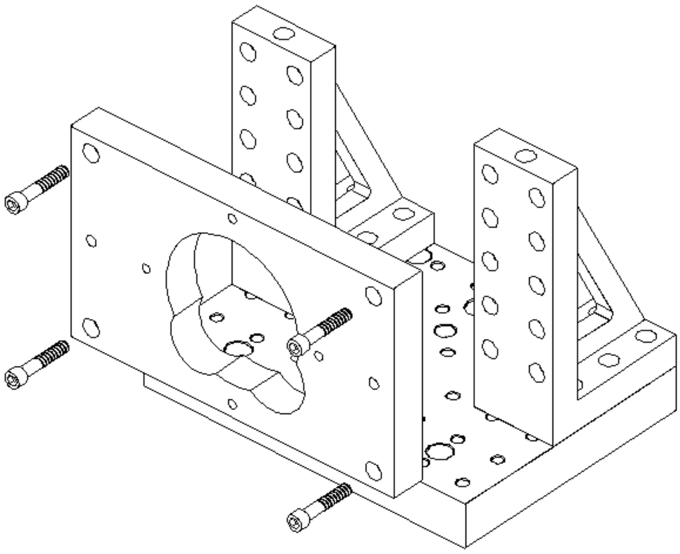


Figure 7-15. Extension of the MCF elements with an adaptor plate [14]

Figure 7-16. Holding fixture constructed from modular fixture components (AMF)

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Module_4

Industrial Technology

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Design of Machinery Fixtures

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