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DESIGN OF SPECIAL MACHINE RETAINING DEVICES

Study guide
for term paper and diploma designing

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The following study guide provides main information on special machine retaining devices, their design and purpose.

Particular attention is paid to the matters of machining precision; appearing of inaccuracies while basing the workpieces and coordinating the tooling are reasoned.

The study guide states theoretical regulations and design technique of special machine retaining devices. It also includes schemes and design of the elements of machine retaining devices.

Intended for the students studying the subjects connected with aircraft and helicopter engineering, aircraft production, and also with computer-aided design.

Представлены основные сведения о специальных станочных приспособлениях, их устройстве и назначении.

Особое внимание уделено вопросам точности обработки, описаны причины возникновения погрешностей при базировании заготовок, координации инструмента.

Изложены теоретические положения и методика проектирования специальных станочных приспособлений. Приведены схемы и конструкции элементов специальных станочных приспособлений.

Для студентов, изучающих дисциплины, связанные с самолето- и вертолетостроением, производством летательных аппаратов, а также с системами автоматизированного проектирования.

Fig. 37. Tables 9. Bibliographic list: 17 titles

Reviewers: laureate of the State prize of Ukraine V.I. Zayats,
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INTRODUCTION

Machining attachments include the following: machine retaining devices, cutting, measuring and backup tooling, and checking fixtures. The costs of producing machining attachments make up 15…20% from the costs of equipment for technological process of machining. Machine retaining devices have the largest specific weight by cost and labor intensiveness of production in total amount of various types of machining attachments.

Complexity of the technological processes of details' production stipulates the usage of a large number of various machining attachments' constructions.

Using machining attachments allows the following:

- eliminating the work layout before machining, to improve the details' accuracy of manufacturing;
- getting a rapid increase in labor productivity during technological operations;
- making labor conditions easier and providing safety of work;
- expanding manufacturing capability of the equipment;
- organizing multimachine manning;
- using technically based time norms and cutting the number of workers needed for production.

Frequent change of production facilities, typical for production of the units for aeronautical and rocket-and-space engineering requires creating the design of constructions, methods of their calculation, and appliances that cut the terms of production planning.

1 GENERAL INFORMATION ON MACHINE RETAINING DEVICES

Machine retaining devices are additional (auxiliary) gears for metal cutting machines. They are used for the following purposes:

- installing the machined workpieces according to the technological process demands when running the machine;
- improving accuracy and stability of surfacing, which is carried out by proper locating, secure workholding of a workpiece and stiffening it while machining;
- increasing labour productivity, which is reached by the following:
  - eliminating the work layout before machining,
  - adjusting the workpieces when installing them,
  - cutting the machining floor-to-floor time in all machining technological operations.

1.1 Classification of machine retaining devices

All the devices are classified by the specialization degree, number of installed workpieces, mechanization and automation levels, and machine types.

According to ГОСТ 31.010.01-84, by *the specialization degree*, the devices may be multipurpose, specialized and special.

Multipurpose devices are the devices for installing the workpieces of various constructions in the dimensions adjusting range. Usually, these devices are included in the tooling package that goes with the machine. They are widely used in single-piece and short-run production, and partly in series production. These devices provide installation of different-sized workpieces without repurposing or adjusting the full jaw or vice grip movement, or turning the table within the range of the device's size.

Specialized devices are the devices for installing the single-type workpieces, i.e. the workpieces that belong to one classification group that is singled out according to the constructional and technological characteristics adjacency. These devices are used in short- and medium-length production. Such devices are readjustable, and to this type belong prefabricated demountable and master devices.

Structural configuration of the assembly-and-disassembly devices (ADD) consists of a base standardized unit and a set of changeable accessories that includes normalized location, clamping and directional accessories needed for treating a certain workpiece. ADD are referred to multiple action devices.

Group devices are used for treating a certain predetermined number of workpieces on a particular operation. They consist of a base standardized unit and a set of changeable accessories. The base unit is standard for the particular number of workpieces, and changeable accessories are special-purpose. When designing a group device, the base unit and the full set of changeable accessories are made at the same time. When treating each item of the workpiece, one makes a repurposing, i.e. installs the proper changeable accessory.

Special devices are the devices used for installing the workpieces of the same dimension type. They are used in serial and mass serial production for installing a particular workpiece when performing a certain operation.

Modular accessories (MA) are the devices that are assembled from a set of standardized elements – details, units, mechanisms. The MA elements are universal, and the assembled device becomes special as it is intended for installing a particular workpiece on the performed operation. After treating the given type of the workpieces, the device is disassembled, and its elements are used for assembling and for other devices. This way, the MA elements are repeatedly used for reassembling the devices. These devices are widely used in single-piece and short-run production.

By the number of the workpieces installed, the devices may be one-position – for installing of one workpiece, and multi-position – for simultaneous installation of several workpieces.

By the level of mechanization and automation, the devices may be:

- manual, in which the workpiece attachment and detachment is carried out by hand;
- mechanized, in which the workpiece attachment and detachment is carried out by means of hydraulic, pneumatic or magnetic drives;
- semiautomatic, in which the given operation algorithm performed is partly human-aided;
- automatic, automated technical devices that are not human-aided.

By the type of machine, the devices may be turning, drilling, milling, grinding, etc.

1.2 Specifications of machine retaining devices

When performing any operation using the device the expected working error mustn’t exceed the given permissible error for a particular geometric parameter, i.e.

$$\boldsymbol{\omega} \leq \boldsymbol{T}, \tag{1.1}$$

wherein $\boldsymbol{\omega}$ is the expected resultant working error of the particular geometric parameter; $\boldsymbol{T}$ is the tolerance given for the geometric parameter (size, shape or positional relationship of the objects).

The resultant error includes several production errors that are joined into two component groups: ω_{inst} **-** workpiece installation error, and $\omega_{proces\,sin\,g}$ - workpiece processing error, then

$$\omega = \omega_{inst} + \omega_{proces\,sin\,g} \leq T\,, \tag{1.2}$$

whence

$$\omega_{inst} = T - \omega_{proces\,sin\,g}\,. \tag{1.3}$$

From the equation (1.3), we can see that the permissible processing error that is connected with the workpiece installation into the device ω_{inst} is the part of the tolerance T . This way, the device precision calculation is brought to determining the expected (estimated) installation error that mustn't exceed the permissible error ω_{inst} .

Production errors included in $\omega_{proces\,sin\,g}$ may be found in the statistic data tables [12]. Basing upon the analysis, one determines production errors that appear during processing and that influence the particular geometric parameter; then their value is determined, and after that ω_{inst} is calculated using the probabilistic summation method.

The main thing for the devices' constructor is to determine the expected error of the installation. This error depends mainly on the choice and accuracy of the setting bases, construction, strength and wear of the devices' installation elements.

The installation error is made up from the following components: basing error ω_b , fixation error ω_f , and device manufacturing and wear error ω_{dev} . The error components stated above are determined by calculation. When determining ω_b , ω_f , ω_{dev} , the designer doesn't have all valid data available, that is why there is no opportunity to get the values of these errors accurate enough. It is recommended to foresee the device accuracy reserve of 10…20%. The installation error is estimated according to the to the variate summation rules by the following formula

$$\omega_{inst} = 1{,}2\sqrt{\omega_b^2 + \omega_f^2 + \omega_{dev}^2} \tag{1.4}$$

The estimated error ω_{inst} is inserted into the formula (1.3). If this error exceeds the permissible value, it is necessary to reduce ω_{inst} at the expense of increasing the device accuracy or changing the way of basing. After that, the recalculation is carried out.

1.3 Basing the workpieces while cutting

The terms and definitions of basing and bases are set in ГОСТ 21495-76 and ДСТУ 2232-93.

Basing is giving a workpiece or an item the required position relatively to the chosen coordinate system.

Base is a surface, axis, or point belonging to the workpiece or the item, that are used for locating.

By the *purpose*, the bases may be of three types: assembly, technological and measuring.

Assembly bases are used for defining the position of the detail in the item. Assembly bases may me main and auxiliary. Main base is for determining the position of the given detail, and auxiliary base is for determining the position of the detail that is attached to the given one.

A base is called ***technological*** if it is used for setting the workpiece or item position while making or repairing it.

Measuring base is used for determining the relative position of the workpiece or item and measuring means.

The laws of basing are the same for all stages of the item making. Independently from the bases' purpose, they are classified by the display character (hidden and explicit) and by the degree of freedom withdrawn from the based workpiece, detail or assembly unit (installation, directing, resting, double directing and double resting) as well. ***Bearing arrangement*** is the set of three bases that form the workpiece coordinate system.

Under ***the hidden*** base we understand the one in the form of a relative plane, axis or point (construction horizontal of an aircraft, wing chord plane, etc.). The base that has the form of a real surface, dimensional mark or the marks' intersection point is called ***explicit.***

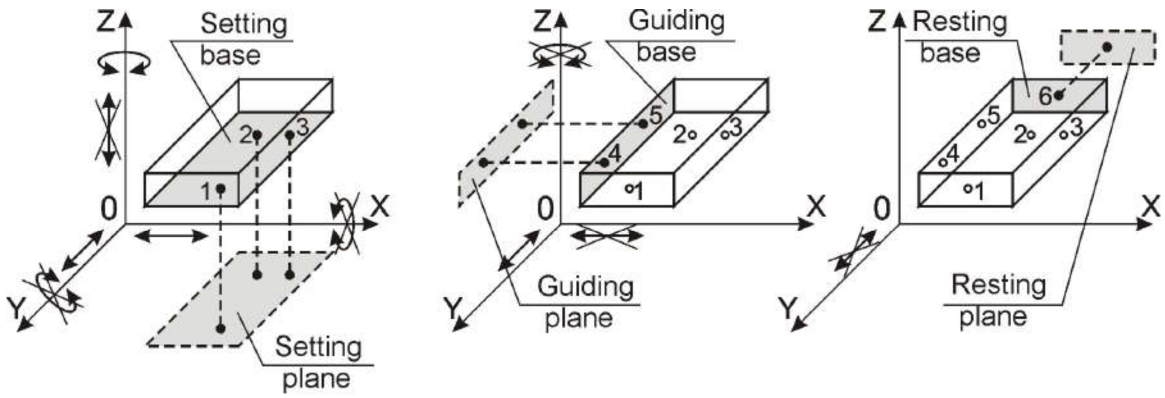
In a simplified way, it is considered that the contact of touching bodies occurs in the control points that symbolize every connection of the workpiece with the chosen coordinate system. The placement scheme of the control points on the bases is called ***basing scheme***. In order for the workpiece to be in a constant position and to counteract the cutting forces, one applies forces towards it with the help of clamps, and they carry out the force closure in the chosen coordinate system. Graphical designation of the bearings and the clamps is set in ГОСТ 3.1107-81 (see the application). For the oriented position of the workpiece in the chosen coordinate system, one needs to apply six bidirectional geometric constraints (withdraw six degrees of freedom). Every control point withdraws one degree of freedom from the detail. Excessive control points (more than six) make the basing scheme statically indefinable and lessen the installation accuracy.

This way, the purpose of machine retaining device is providing the workpiece with definite and stable position in space relatively to the cutting tool trajectory according to the rule of six points.

The rule of six points: For the full basing of the workpiece in space, it is necessary to have the set of three orthogonal planes that carry six control points.

The details of airplanes, helicopters and aircraft made by dimensional processing of cutting are, as a rule, of a complex geometric form. But it is possible to single out the typical geometric surfaces on the details – flat, cylindrical, conical, etc. As an example, let’s consider the basing schemes of prismatic and cylindrical workpieces.

The basing of prismatic workpieces is shown in the Fig. 1.1.



a b c

Figure 1.1 – Prismatic workpiece full basing scheme:
a – setting base, b – guiding base, c – resting base

In order to withdraw three degrees of freedom from a prismatic workpiece (moving along the ***Z***-axis and rotation along the ***X***- and ***Y***-axes are possible), one should tie its lower surface with the ***XOY***-plane with three rigid bidirectional constraints 1 – 3 (Fig.1.1, a).

The base used for applying the constraints that withdraw three degrees of freedom from the workpiece (moving along one coordinate axis and rotation along two other axes) is called ***the setting base***.

In order to withdraw two more degrees of freedom from the workpiece (moving along the ***X***-axis and rotation along the ***Z***-axis are possible), one should tie its lateral surface with the ***YOX***-plane with two rigid bidirectional constraints 4, 5 (Fig.1.1, b).

The base used for applying the constraints that withdraw two degrees of freedom from the workpiece (move along one coordinate axis and rotation along another axis) is called ***the guiding base.***

In order to withdraw one degree of freedom from the workpiece (moving along the ***Y***-axis is possible), one should tie its end surface with the ***XOZ***-plane with one rigid bidirectional constraint 6 (Fig.1.1, c).

The base used for applying the constraint that withdraws one degree of freedom from the workpiece (moving along one coordinate axis or rotation along the same axis) is called ***the resting base***.

For prismatic workpieces, it is recommended to choose the surface with maximum overall dimensions as a setting base, the surface with maximum length as a guiding base, and the shortest surface of the workpiece as a resting base.

The basing of cylindrical workpieces is shown in the Fig. 1.2.

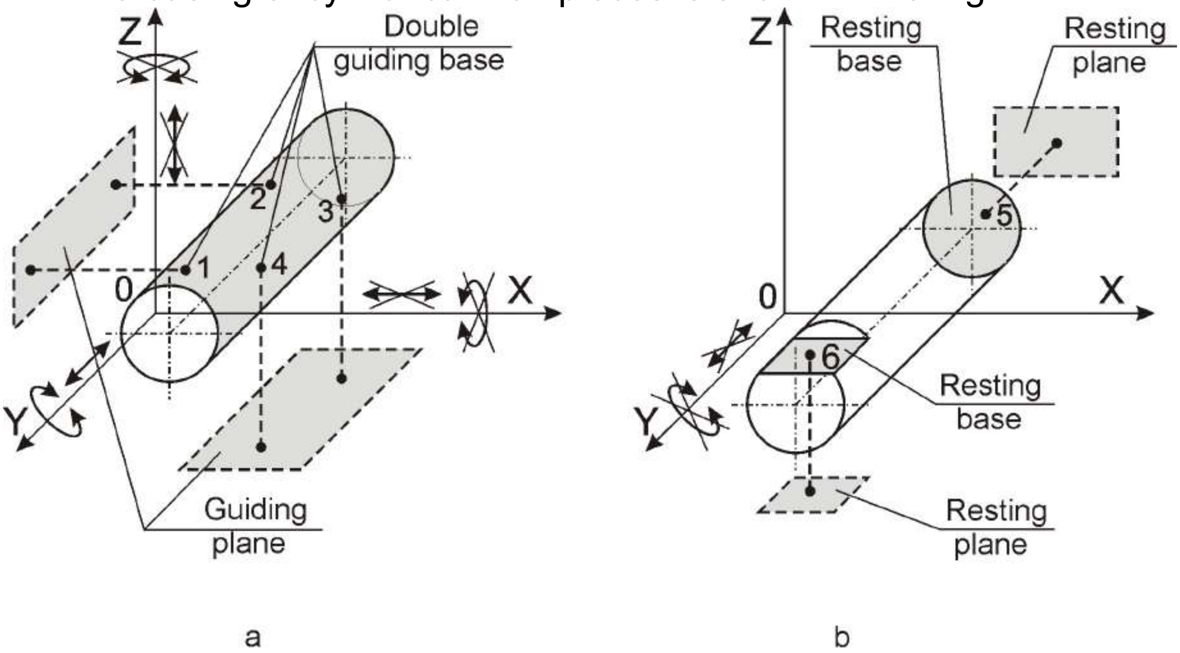


Figure 1.2 – Cylindrical workpiece full basing scheme:
a – double guiding base; b – resting bases

In order to base a cylindrical workpiece its lateral area is joined with the constraints 1, 2 with the plane $\boldsymbol{YOZ}$, and with the constraints 3, 4 – with the plane $\boldsymbol{XOY}$, withdrawing four degrees of freedom from the workpiece – the possibility of moving along the $\boldsymbol{X}$- and $\boldsymbol{Z}$-axes, and also rotation along these axes (Fig.1.2, a). The surface of the cylindrical workpiece that carries four control points is ***the double guiding base***.

To disable a cylindrical workpiece from moving along the $\boldsymbol{Y}$-axis, it is necessary to join its side with the constraint 5 with the plane $\boldsymbol{XOZ}$ (Fig.1.2, b). In order to provide a certain position of the workpiece with respect to its own axis, the constraint 6 in the form of a control point on the surface of a spline flat, for example, should be foreseen. The workpiece planes that are bearing by one control point, according to the definition given earlier serve as resting bases.

The rules for choosing the technological bases

The following principles lie in the basis of the technological bases' choosing technique:

– one chooses the basing scheme that provides minimum installation error;

– in order to increase the details' production accuracy one uses the principle of bases' joining: assembly, technological, measuring bases;
– it is reasonable to follow the base constancy principle. When changing the bases during technological progress, the accuracy of machining drops because of the relative position of new and earlier used technological bases.

The technique of choosing the technological bases:
– basing upon the analysis of the construction, purpose of the detail and assembly unit, construction dimensioning and tolerance construction bases are determined;
– as the preferable set of technological bases, the corresponding set of construction bases is chosen;
– the possibility of machining the details' different surfaces is viewed sequentially depending upon the chosen set of the technological bases;
– the chosen type of basing is checked for the correspondence of accuracy and the possibility of carrying out technological operations in a certain working environment.

For example, in the case of drilling the holes with the help of a manual power tool it is necessary to take into consideration the possible disbalance of the hole's axis as a result of the clearance between the hole in the drill bushing and the drill (Fig. 1.3).

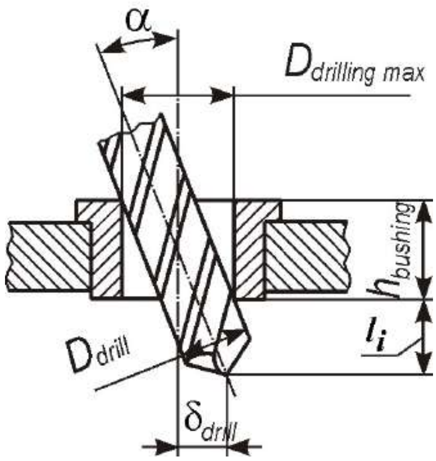


Figure 1.3 – Disbalance of the drill in the drill bushing

In this case the drill axis run value is

$$\boldsymbol{\delta_{drill}} = \frac{\boldsymbol{l_i}}{\boldsymbol{h_{bushing}}}\left(\boldsymbol{z_{max}} + \boldsymbol{k}\,\frac{\boldsymbol{l_i} + \boldsymbol{h_{bushing}}}{\boldsymbol{100}}\right), \qquad (1.5)$$

where l_i is the distance between the lower end of the bushing to the top of the drill; $\boldsymbol{h_{bushing}}$ is the drill bushing height; $\boldsymbol{z_{max} = D_{drilling\,max} - D_{drill\,min}}$ is maximum clearance between the drill and the drill bushing, considering its wear ($D_{drilling\,max}$ is maximum drill bushing diameter; $D_{drill\,min}$ is minimum drill diameter); k is the drill reverse taper.

When developing the basing system, one makes an operational draft, on which the positions of bearings and clamps are shown. With that, all the information is marked using the symbolic notations according to ГОСТ 3.1107-81 "Bearings, clamps and location bracketry. Graphical symbols" (see the application). Bearings and clamps are marked with the thin solid line according to ГОСТ 2.303-68, and workpiece machining areas are marked with the base solid line that is two-three times thicker than the solid line provided in the same ГОСТ (Fig. 1.4).

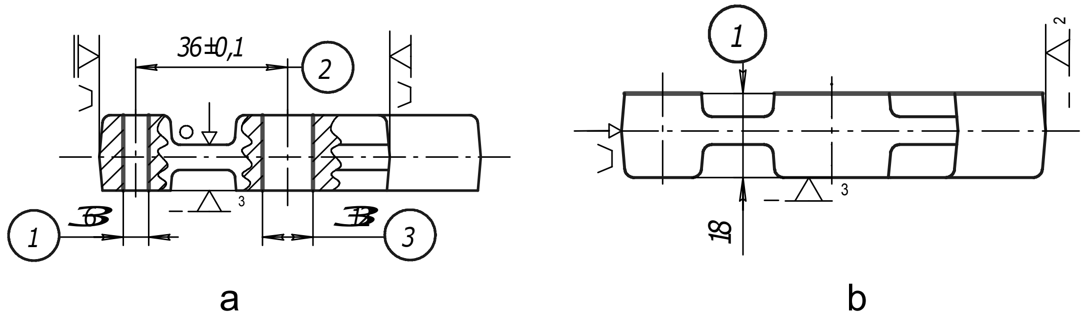


Figure 1.4 – Operational draft for treating: a – two holes by drilling; b – a plane by milling

Besides, the operational draft has to contain the following data to carry out the operation (operating step): necessary sizes, extreme deviations, designations of surface finish, technical requirements, etc.

The operational draft shows the treated workpiece in the way it should look after the operation carried out.

1.4 Elements of machine retaining devices

Despite the large variety of used devices' constructions, all of them have common structure, which allows dividing the constructions by their functionality into separate parts. Such parts of the constructions are known as elements.

An element is a detail, assembly unit, mechanism, device or unit used for carrying out a certain function in the device. Construction analysis shows that the number of elements in the devices' structure is fairly small.

All elements may be united into the following main groups: installation, chucking, directional, separatory, frame, and auxiliary elements. In the group, the elements differ not only by their size, but also by embodiment. Depending upon the purpose, the device's construction may consist of the whole set of elements or only of separate groups of elements.

The elements are designed with consideration of the requirements that are demanded from them upon the basis of their function. This allows using general design methods for every group of elements. That is why there is no need to consider a great number of the elements' construction variants or devices' constructions in order to identify the design regularities.

2 LOCATION ELEMENTS OF MACHINE RETAINING DEVICES

2.1 Purposes and specifications of location elements

When locating, the workpiece should be correctly oriented with respect to the machine movable operating elements. Locating is basing and fixing a workpiece in the device. Workpiece orientation is reached by workpiece basing.

For basing the workpieces, one uses location elements of the devices that are fixedly connected with the device's frame. Location elements are made in the form of bearing plugs, plates, rings, bushings, fingers, and prisms.

For carrying out the operation, it is necessary not only to base the workpiece, but also to fix it immovably with respect to the device that ensures its immobility. That is why when locating the workpieces into the devices, two tasks are solved: the workpiece orientation, which is carried out by basing, and providing its immobility (fixation). These tasks are solved by means of imposing certain restrictions (bounds) on possible shifts of the workpiece in space.

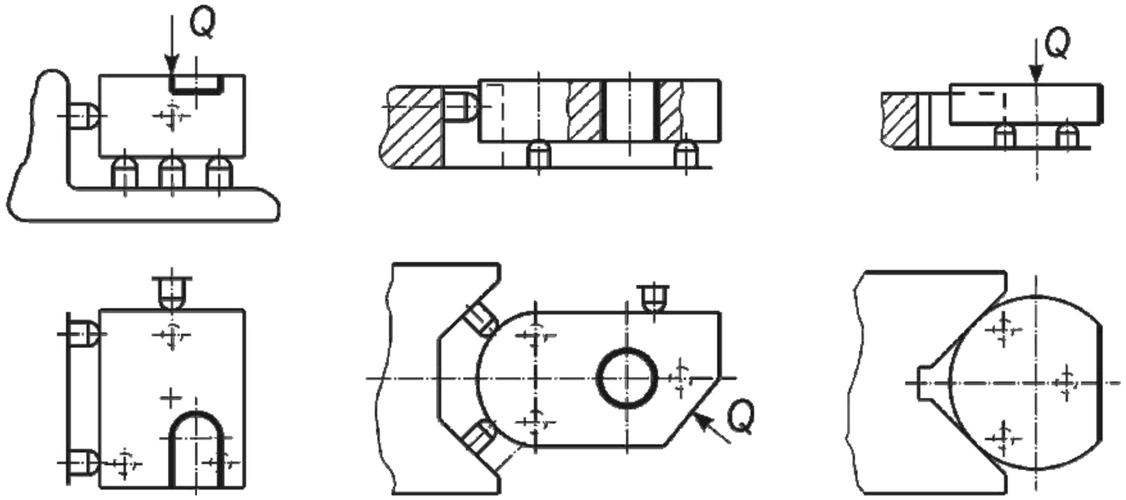
It is known that for complete elimination of mobility of a solid body in space, it is necessary to withdraw six degrees of freedom from it: move and turn relatively to the three coordinate axes. Therefore, for locating the workpiece, it is necessary to apply six bidirectional coordinate constraints applied in the control points. This way, in order to withdraw six degrees of freedom from the workpiece, it should have six contact points with the location elements (the rule of six points), each withdrawing one degree of freedom.

Depending on the machining conditions, there may be full orientation, when the workpiece is based upon six control points, and partial, when there is less than six control points.

Fig. 2.1 shows the examples of installations with their full and partial orientation in space.

After fixing the workpiece, a closed system *workpiece –bearings – device frame - clamping device* is formed. The force ***Q*** is taken by the elements of this system.

Fig. 2.1, a, b shows us the locating schemes with basing on flat and curved surfaces with the workpieces' full orientation. Fig. 2.1, c gives an example of the workpiece partial orientation. With its flat face, it is based on three points, and its cylindrical surface touches the other two points. As the ground (shown with a bold line) may be machined in any place, five control points will be enough for locating the workpiece.



a B c

Figure 2.1 – The examples of locating the workpieces with full (a, b) and partial (c) orientation

One should mind the following: the workpiece basing in the device is provided by main installation elements, and as for additional (auxiliary) elements (support), they don't participate in basing, but they add firmness and rigidity to the workpiece. The support is movable, it is brought to the workpiece after fixing it on the main bearings. The devices' point support is practically represented with support structures. They include fixed support, supporting plates, V-blocks for installing cylindrical workpieces. They provide reasonable firmness of the workpieces independently of their shape and size inaccuracies. The lower is the precision and the more is the ruggedness of the workpiece base surfaces, the more their contact places with the devices' bearings are localized. It is possible to install the workpieces with one base on the bearings that have larger contact surface, and with other bases on the point support.

Besides installing the workpieces with their base surfaces' full pressing to the device bearings, installation by wraparound or terminal base surfaces is used. In the process, the workpiece is put on the installation element or is put into it with some backlash allowance.

Fig. 2.2 shows the combined installation scheme. The workpiece ***M*** is put with its pilot hole with the clearance on a rigid finger ***F*** and is pressed tightly with its end surface to its clamp.

For installation schemes by wraparound or terminal base surfaces with the workpiece full orientation in space, the rule of six points is also used (see Fig. 2.2).

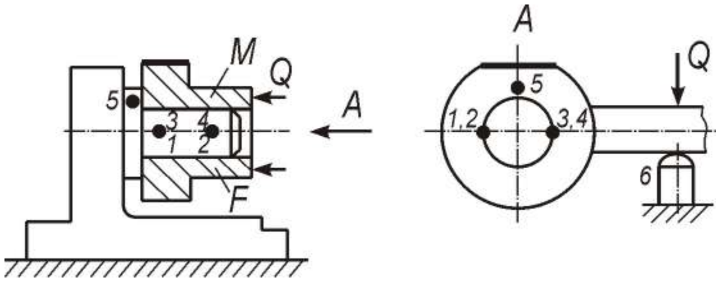


Figure 2.2 – Combined workpiece installation scheme

In accordance with the general rules of the workpieces' installation to the location pieces, the following demands may be raised:

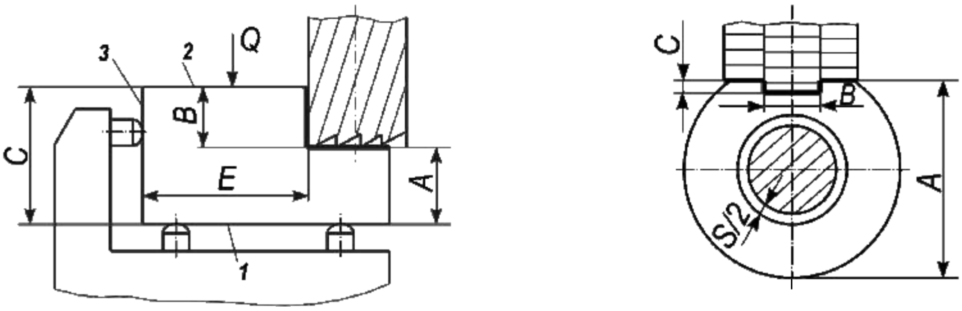
– the number and arrangement of the elements should provide orientation of the workpiece with the given accuracy according to the basing scheme accepted in the technological process and its proper stability in the device;
– when using the necessary bases with the workpiece surface roughness parameter of more than $\boldsymbol{R_a 20}$ micrometer, the location pieces should be made with limited bearing surface in order to lessen the impact of these bases' roughnesses on the workpiece stability.

2.2 Typical installation schemes of the workpieces

Detail accuracy parameter provided during machining is the result of the technological system functioning. Technological system consists of separate elements (machine – device – instrument – workpiece), with each of them influencing the working error.

Workpiece setting error $\omega_{setting}$, as one of the components of the carried out geometrical parameter total error, is summed up of basing ω_b and attachment ω_a errors, and of blank position error caused by the device manufacturing and wear inaccuracy ω_{device} according to the formula (1.4). By its physical interpretation, the value $\omega_{setting}$ shows the workpiece location error.

Basing error ω_b is the deflection of actually reached position of the workpiece from the required one by basing. This error is a geometrical value. For the given basing scheme, it is defined as the projection of the distance between end positions of the measuring bases in the line of the size received by machining. It may be different for the same basing scheme. When matching the measuring and technological (setting) bases, the basing error is close to zero. By machining the batch of workpieces (Fig. 2.3, a), the basing error relatively to the size $\boldsymbol{A}$ is equal to zero, as the measuring and setting bases match in the plane 1 of the workpiece. The basing error relatively to the size $\boldsymbol{B}$ is equal to the tolerance on the size C of the workpiece. In this case, the technological base (plane 1) doesn't match with the measuring base (plane 2). The basing error relatively to the size E will be equal to zero, as the workpiece 3 plane is at the same time the setting and measuring base.



A b

Figure 2.3 – A scheme for determining the workpiece basing error:
a – prismatic; b – with central hole

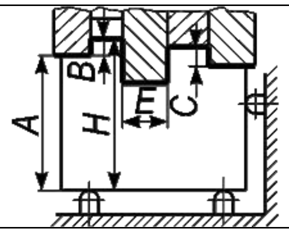
The schemes for determining the workpiece basing error with the central hole on the device cylindrical finger is given on the Fig. 2.3, b. When fitting without the clearance (expanding finger), the basing error for the size A is equal to the half of the tolerance on the workpiece size. When there is the clearance S, the basing error for the same size increases on the value of the clearance limiting measuring. In all cases the basing error is equal to zero for the diameters of machined workpieces and sizes determining the mutual position of the surfaces machined by made-to-measure and qualified tooling. Thus, for the sizes B and C (see Fig. 2.3, b), the basing error is equal to zero.

Let us consider typical workpiece installation schemes in the devices that are most widely used when manufacturing the details by machining.

2.2.1 Installing the workpiece by their base planes

Workpiece basing errors for typical installation schemes on the plane are given in the Table 2.1.

Table 2.1 – Workpiece basing errors by installation on the plane

Installation scheme	Dimension held	Basing error
	A B C E	$\omega_{bA} = 0$ $\omega_{bB} = T$ $\omega_{bC} = 0$ $\omega_{bE} = 0$

Carrying out the workpiece flat surface basing means matching it with a given device surface. As the position of any plane is defined by three points, in order to base, it is necessary for the device to have three control points that lie in the given plane, but don't lie in the same line. This is reached with the help of various combinations of main supporting structures that determine the way of flat base basing.

Rigid support is made in the form of pins (Fig. 2.4). The pins for machined bases should have a flat head (Fig. 2.4, a), with their diameter chosen depending on the base area. The pins shown in the Fig. 2.4, b and c, serve only for orientation of non-machined bases. The supporting pins should be set as far from one another as possible, as it increases the basing accuracy.

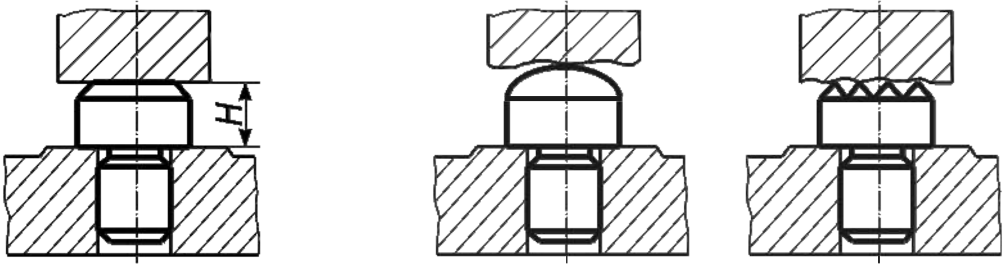


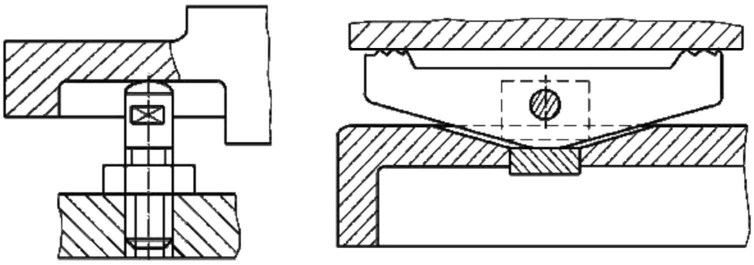
Figure 2.4 – Supporting pins

The design of supporting pins is standardized – according to ГОСТ, they are called ***fixed support***. The pins are made with flat (ГОСТ 13440-68), ball-shaped (ГОСТ 13441-68) and knurled heads. The holes for the pins in the device frame are made through, pin coupling with the holes is interfit by $\boldsymbol{H7/n6}$ or $\boldsymbol{H7/p6}$. On the device frame in the places of pins installation, the areas (usually on the heights) are provided; these areas are machined simultaneously. When the pin head height $\boldsymbol{H}$ is made accurately, with the workmanship inaccuracy $\boldsymbol{h5}$ or $\boldsymbol{h6}$, all the pins' bearing surfaces are situated in the given plane.

Sometimes for basing the workpieces with raw flat base, adjustable legs are used instead of the specified supporting pins (Fig. 2.5, a), so that the legs' height could be altered according to the rough tolerance value of the workpieces from different batches. The adjustment is carried out before machining of each workpiece batch with new rough tolerance. After the adjustment, the legs' position is fixed and stays unchangeable during machining of all workpieces in the batch.

Adjustable legs' design is regulated by ГОСТ 4084-68, ГОСТ 4085-68, and ГОСТ 4086-68.

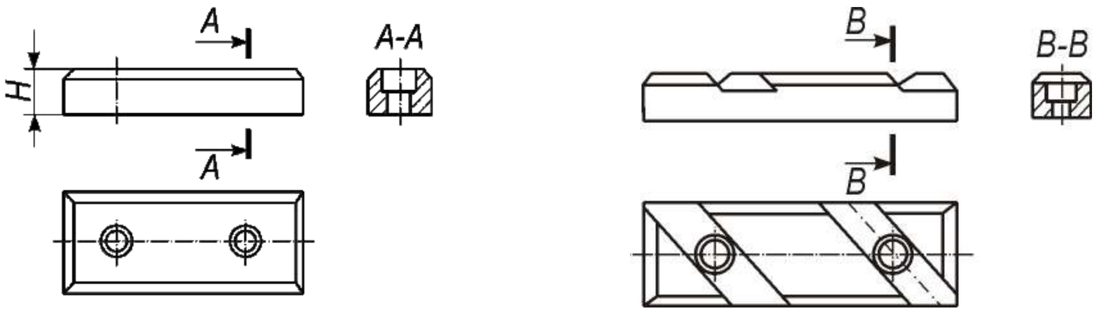
When installing, non-rigid workpieces in the device may be deformed under the impact of fixation forces, and when machining, they may be deformed by cutting forces. In order to increase the rigidity, one tends to increase the contact area of the workpiece and the device without breaking the demands of theoretical mechanics – for determining the position of a plane three points are necessary and sufficient. This is reached by using interlocked (Fig. 2.5, b) and floating bearings, with each of them substituting one supporting pin, although it contacts the base in two or three points. The design of such bearings provides conformed relocation of bearing surfaces, by which the position of the control point stays practically unchangeable (it remains in the given area of the device).



a b c

Figure 2.5 – Examples of workpiece installation on the bearings:
a – regulated; b – interlocked; c – floating

Basing with the help of ***support blades*** is the most widespread way of machined bases orienting. According to ГОСТ 4743-68, support blades are of two types: flat (Fig. 2.6, a) and with sweep slots (Fig. 2.6, b). The bearing surfaces of the latter are easier cleaned from the shaving, that is why they should be used for installing in the horizontal plane, and flat slots should be installed on the side surfaces. The blade length is chosen depending from the base length. Support blades are usually placed on the height areas of the device frame. When manufacturing the device, the areas are machined simultaneously, the blade height ***H*** is kept with the workmanship inaccuracy ***h6***.



a b

Figure 2.6 – Supporting blades: a – flat; b – with sweep slots

If by basing in the ways mentioned above the workpiece doesn't get enough stability or rigidity, the necessary auxiliary bearings should be added to the main supporting elements.

Auxiliary supporting elements are brought to the workpiece after it has received the necessary basing main bearings. This helps to prevent possible workpiece deformations under the influence of cutting and fixation forces.

According to their design, auxiliary bearings may be adjustable (screw), underpropped (wedge-like), self-centered (spring).

2.2.2 Installing a workpiece by a base hole and a plane

Basing a workpiece by a hole means matching its axis with a given line in the device. Such basing scheme in the device may be received by using fingers and mandrels as installation elements.

Basing of a workpiece with its internal cylindrical surface on a cylindrical finger is shown in the Fig. 2.7. The workpiece is installed with its hole on a cylindrical finger made with such declination that the workpiece-finger joint has clearance fit.

As the workpiece is installed on the finger by clearance fit,

$$d = D - S_r , \qquad (2.1)$$

wherein d is finger maximum diameter, D is hole minimum diameter, S_r is clearance provided by the fit.

Maximum clearance in the joint is

$$S_{max} = S_r + T_d + T_D , \qquad (2.2)$$

wherein T_d , T_D are tolerances on finger and hole manufacturing.

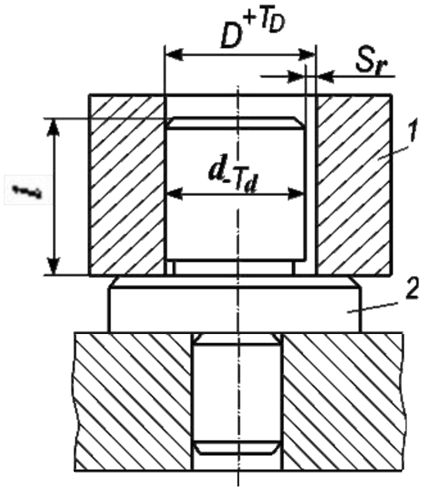


Figure 2.7 – Basing scheme of workpiece 1 on cylindrical finger 2

In this case the basing error (beating) will be equal to maximum clearance $\omega_b = S_{max}$, the shift of the base axis with respect to the clearance is calculated by the formula

$$\alpha = arctg \frac{S_{max}}{l} , \qquad (2.3)$$

wherein α is the base turn angle, l is the finger length.

In order for the base axis shift not to exceed the permissible limits, finger length ***l*** is considered to be about ***1,5D***, whereas ***D*** is base hole nominal diameter.

The viewed way of basing is used only for the workpieces with base holes machined by workmanships 6 to 9, else large errors and base axis shit occur. Sometimes in order to increase the workpiece accuracy, it is installed on the finger not by clearance fit, but by transition fit or even by stationary fit (is forced on). In this case the base axis error is equal to zero. This way is usually used by machining the workpieces on the mandrels installed in machine centers.

Constructional varieties of the fingers are given in the Fig. 2.8. The fingers' design is standardized by ГОСТ 12209 – 12212-66. Fig. 2.8, a, c shows fingers with collars, and Fig. 2.8, b, d – without collars. The fingers with the diameter of more than 16 mm are made of 20X steel with cementation on the depth of 0,8...1,2 mm and hardening up to HRC 49...54. The fingers' working surface is treated by seating fits ***H7 / g8*** or ***H9 / g8*** and ground up to $\boldsymbol{R_a}$ = 0,63...0,32 micrometer.

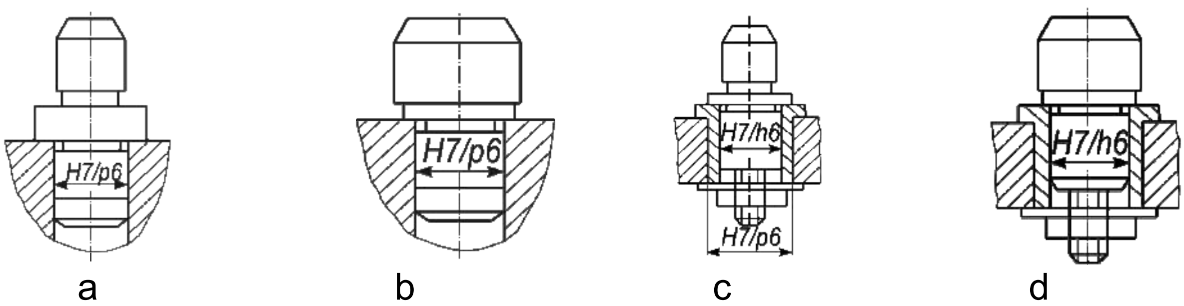


Figure 2.8 – Installation fingers: a, b – constant, c, d – changeable

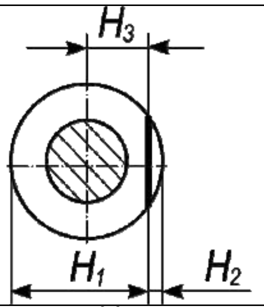
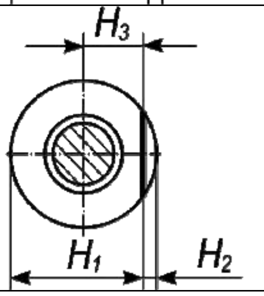
Finger installation error is characterized by the workpiece shift on the diameter clearance between the joining points. If the workpiece base end is unorthogonal to the hole axis, the hole axis may decline from the finger axis. Table 2.2 shows basing errors for typical workpiece installation schemes on fingers and mandrels.

The workpiece position by its length is defined by collar mandrel; its turning is prevented by the screw nut gripping. For these mandrels, it is recommended that the workpiece base holes are machined by workmanship 7. The centering accuracy depends on the clearance and is usually 0,02...0,03 mm.

The mandrels are made of 20X steel, cemented on the depth of 1,2...1,5 mm and hardened up to HRC 54...59. The neck working surfaces are ground up to $\boldsymbol{R_a}$ = 0,63...0,32 micrometer.

Usually the mandrels have on-centre nests, and for passing the turning moment the square, flats or driving bolt are made on the end of the mandrel. The mandrels with the diameter of more than 80 mm are made hollow to reduce its mass.

Table 2.2 – Basing error for typical installation schemes on fingers and mandrels

Installation	Installation scheme	Dimension held	Basing error
Pinch		H_1 H_2 H_3	$0{,}5T_D + 2e$ $0{,}5T_D + 2e$ $2e$
Clearance		H_1 H_2 H_3	$0{,}5T_D + 2e + T_d + T_F + 2S$ $0{,}5T_D + 2e + T_d + T_F + 2S$ $2e + T_d + T_F + 2S$

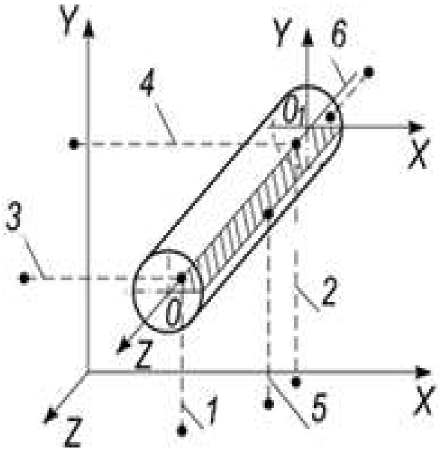
Note: e is external surface eccentricity relatively to the hole; T_d and T_F are tolerances on the finger and hole diameter, mm; S is minimum radial clearance, mm; T_D is workpiece external diameter clearance, mm.

2.2.3 Installing a workpiece by external cylindrical surface

External cylindrical surface is widely used by basing such workpieces as shafts, bushings, etc. Depending on the ratio of the length l and diameter d of the workpiece, there are two schemes that differ by the distribution of control points between the cylinder and the end plane.

Workpiece base cylindrical surface with the ratio $l / d \geq 1$ (roller) bears four control points (Fig. 2.9, a). Basing by cylindrical surface withdraws four degrees of freedom from the workpiece. The end carries the control point that prevents the workpiece from moving along the axis. The control point that prevents the workpiece from turning along its longitudinal axis may be set on the keyseat surface.

When basing a cylindrical workpiece with the ratio $l / d < 1$ (disc), control points that lie in the cylinder moving line do not provide steady position for the workpiece. That is why the workpiece flat end that carries three control points is taken for the installation base; cylindrical surface carries two control points (Fig. 2.9, b). The control point that prevents the workpiece from turning along its longitudinal axis may be set on the keyseat surface.



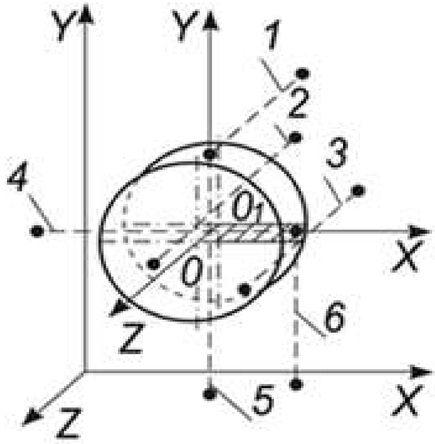


Figure 2.9 – Basing scheme of cylindrical workpieces of roller (a) and disc (b) type

By basing the cylindrical workpiece in the hole (Fig. 2.10), bushing 1, in the hole of which the workpiece is installed, serves as the supporting element. The bushing hole axe is placed in the device in the needed position.

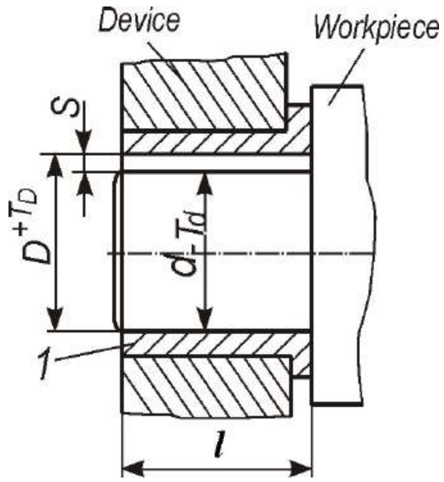


Figure 2.10 – Basing scheme of cylindrical workpiece into the hole

In order for the workpiece to be inserted into the bushing hole, it is necessary to provide backlash allowance.

In this case, the base and hole diameters will be joined together by the relation

$$\boldsymbol{D} = \boldsymbol{d} + \boldsymbol{S_r}, \qquad (2.4)$$

wherein $\boldsymbol{D}$ is minimum bushing hole diameter; $\boldsymbol{d}$ is workpiece maximum diameter; $\boldsymbol{S_r}$ is backslash allowance.

Taking into account the backslash allowance, and also the workpiece production inaccuracies and bushing hole, maximum diameter clearance in the workpiece-bushing joint will be

$$S_{max} = T_D + T_d + S_r . \qquad (2.5)$$

In the range of this clearance, the workpiece base axis may shift relatively to the bushing hole axis in any side on the value of half of the clearance $S_{max} / 2$. Maximum distance between extreme displaced positions of the base axis is base axis basing error ω_b, which is equal to S_{max}, i.e. $\omega_b = S_{max}$.

This way, base axis basing error in this way is

$$\omega_b = T_D + T_d + S_r . \qquad (2.6)$$

Besides, in the range of S_{max}, base axe disbalance is possible; it is determined by the formula (2.3).

This way of basing is used for the workpieces with the bases that are machined by workmanship 7 to 9. In order for the workpieces to be easy installed in the bushing hole, there should be backslash allowance by clearance fit.

When designing the device, length l of the bushing is taken no less than $1,5D$, else large workpiece axis disbalance occurs.

2.2.4 Installing a workpiece on a prism

A prism is an installation element with the working surface in the shape of a slot formed by two planes inclined under the angle α. The prism determines the position of workpiece axis perpendicular to the prism base owing to its matching with the angle slot axis. The angle slot axis is the axis built through the point of intersection of working planes perpendicular to the prism base plane.

In the devices, the prisms with angles α, equal to 60, 90 and 120^o. Prisms with the angles $\alpha = 90^o$ became most widespread. Prisms with the angles $\alpha = 120^o$ are used when the workpiece doesn't have full cylindrical surface, and the position of workpiece axis has to be defined by a short circular arc. The workpiece placed on such prisms has little stability.

Prisms with the angle $\alpha = 60^o$ are used for increasing the workpiece stability in the case when there are significant cutting forces that act parallel to the prism base. When installing the workpieces with clean machined bases, prisms with wide bearing surfaces are used, and for rough bases – with narrow ones.

By installing long workpieces, two prisms installed in alignment are used; after their fixation on the frame, they are ground simultaneously by their working surfaces to reach alignment and equal height. If machining conditions are such that the given workpiece needs to be installed on several prisms, two of them are made rigid (main support), and the rest are movable (auxiliary support).

Let us consider the workpiece installation on the prisms. Fig. 2.11 gives the shaft installation on the prism for machining the flat. The position of the flat in the direction of the Z-axis relatively to the shaft cylindrical position may be set by the designer with one of three sizes B_1, B_2, B_3. For each of these sizes, the same technological base is used: cylinder contact generating lines with the prism working surfaces that pass through the points $F - F$. In all cases, there occurs the basing error connected with the base misfit – technological and measuring.

When measuring the shaft diameter in the batch of workpieces in the tolerance range T_D, the technological base – shaft and prism contact generating lines – changes its position, the base shift occurs. When installing a cylindrical workpiece with the diameter D (Fig. 2.11, b) the technological base passes through the points $F - F$; when the workpiece diameter is $D - T_D$, it shifts into the position $F_1 - F_1$.

According to the Fig. 2.11, a, the basing errors are:

for the size B_1

$$\omega_b = \frac{T_D}{2}\left(\frac{1}{\sin(\alpha/2)} - 1\right); \tag{2.8}$$

for the size B_2

$$\omega_b = \frac{T_D}{\sin(\alpha/2)}; \tag{2.9}$$

for the size B_3

$$\omega_b = \frac{T_D}{2}\left(\frac{1}{\sin(\alpha/2)} + 1\right). \tag{2.10}$$

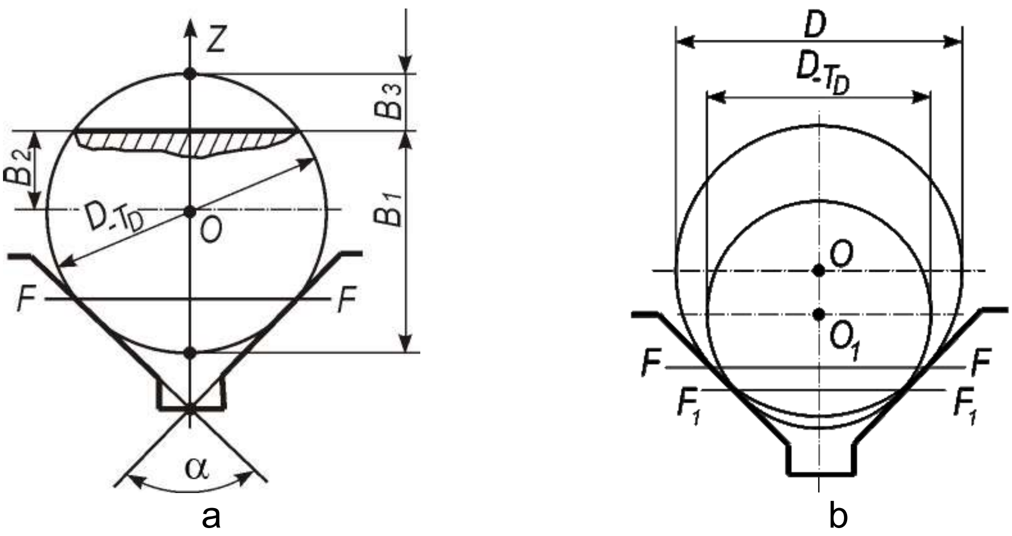
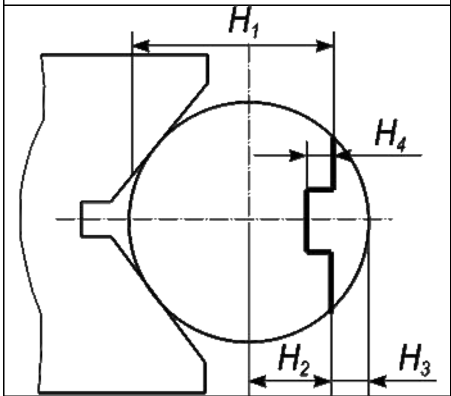
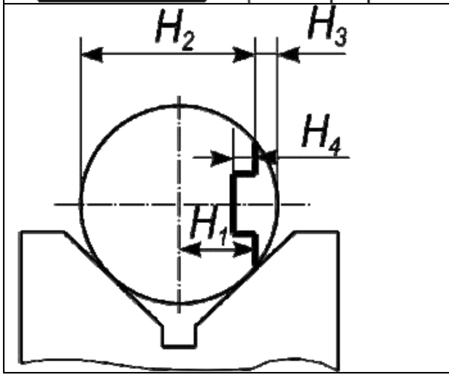


Figure 2.11 – Basing scheme of a cylindrical workpiece on a prism

The constructor may try to increase the manufactured size accuracy without changing the installation base conditioned by the technologist, but by changing the position of the prism relatively to the shaft. Table 2.3 gives typical installation schemes of cylindrical workpieces on a prism and the corresponding manufacturing sizes' inaccuracies depending upon the base surface diameter tolerance.

Table 2.3 – Basing error for the typical workpiece installation schemes on a prism

Installation scheme	Given size	Basing error
	H_1 H_2 H_3 H_4	$\frac{T_D}{2}\left(\frac{1}{\sin(\alpha/2)}-1\right)$ $\frac{T_D}{\sin(\alpha/2)}$ $\frac{T_D}{2}\left(\frac{1}{\sin(\alpha/2)}+1\right)$ 0
	H_1 H_2 H_3 H_4	0 $0{,}5T_D$ $0{,}5T_D$ 0

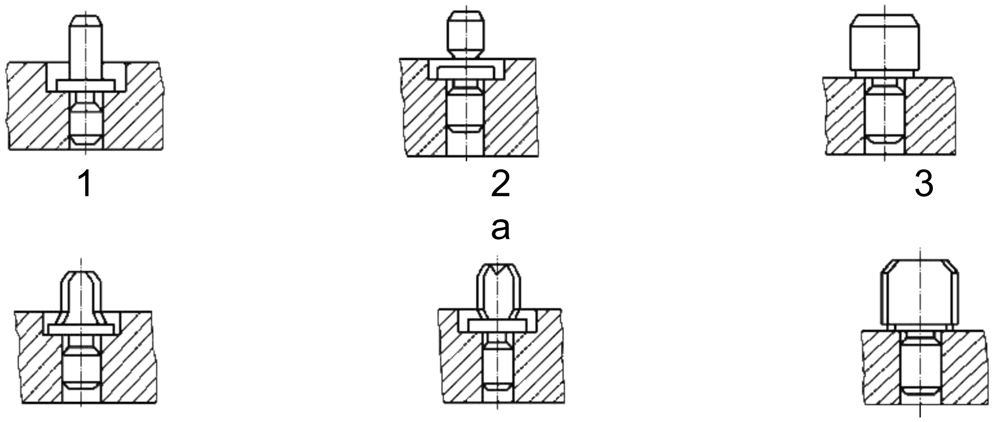
2.2.5 Installing a workpiece by two holes and a plane

Installation by two holes and a plane is used by treating such workpieces as frames and boards. The advantages of this basing scheme are easy device design and possibility of following the base permanency principle on most technological process operations (Fig. 2.12).

By its design, the installation consists of two cylindrical fingers or of one cylindrical and one cut fingers. Usability limits of these combinations are determined by diameters' accuracy, base holes' mutual positions, and demanded accuracy of relative distances and turns of machined surfaces held during the operation.

When designing the devices with two fingers, the constructor always has the task of determining the fingers' diameters, tolerances on their manufacturing and wear, and finger centre-to-centre distance tolerance.

By solving this task, initial conditions for the constructor are the following: providing the installation on two fingers of any workpiece of the treated batch with centre-to-centre distance and hole diameter in the limits of the given tolerance, providing the demanded operational sizes' accuracy.



1 2 3

a

1 2 3

b

Figure 2.12 – Installation fingers: a – cylindrical; b – cut;

1 – $\boldsymbol{D < 10}$ mm; 2 – $\boldsymbol{D = 10...16}$ mm; 3 – $\boldsymbol{D > 16}$ mm

The diameter of one of the fingers is usually set equal to the base hole diameter nominal size, and the tolerance is set by the seating fits ***f6***, ***f7***, ***e9*** depending upon the hole accuracy.

There are conditions that determine the possibility of installing the workpiece on two cylindrical fingers. In order to fulfill the installation condition, let us consider the worst case, when the hole centre-to-centre distance is done by the greatest permissible size $L + T_{M.f}/2$, and the device fingers centre-to-centre distance is done by the smallest one – $L - T_{M.hole}/2$, and the clearances in the couplings of the holes with fingers are made minimum – $S_{1\,min}$, $S_{2\,min}$. The hole axes relatively to the finger axes may shift on the value $S_{1\,min}$ and $S_{2\,min}$. From here we may determine the workpiece installation conditions on two fingers:

$$S_{1\,min} + S_{2\,min} \geq T_{M.hole} + T_{M.f}. \tag{2.10}$$

If it is necessary to choose minimum clearance between the finger and the second hole in the same way as for the first one (by clearance fits ***f6***, ***f7***, ***e9***), the centre-to-centre tolerances have to be very little, as we can see from the workpiece installation condition (2.10). This makes the base holes machining more expensive. Usually the finger and hole distances centre-to-centre tolerances are significantly wider than their diameters' tolerances. That is why in order to keep the workpiece installation conditions on two cylindrical fingers, the diameter of the second finger has to be made significantly smaller.

Let us determine the diameter of the second finger, basing upon the condition that the distance $S_{2\,min}$ is equal to the difference between minimum hole diameter d_{hole2} and maximum finger diameter $d_{f\,2}$, i.e. $S_{2\,min} = d_{hole2} - d_{f\,2}$. When we set this expression into the equation (2.10), we get $S_{1\,min} = d_{hole2} - d_{f\,2} = T_{M.hole} + T_{M.f}$, then

$$d_{f\,2} = \left(d_{hole2} + S_{1\,min} - T_{M.hole} - T_{M.f}\right). \quad (2.11)$$

This way, in order to save the possibility of installing the workpiece on two cylindrical fingers, it is necessary to make minimum clearances in the hole and finger couplings larger, and this often leads to inadmissible reduction of installation accuracy.

It is possible to increase this accuracy significantly, at the same time saving the possibility of installing any workpiece from the batch with base holes centre-to-centre distances in the limits of the given tolerance if the second finger is not cylindrical, but cut.

The finger cut increases the clearance in the direction of the common axis of two base holes, and this helps to install the workpieces with greater tolerance. Similarly to the formula (2.10), the installation condition may look as follows:

$$S_{1\,max} = \sqrt{d_{hole\,2}^{2} + в^{2} - d_{f\,2}^{2}} - b \geq T_{M.hole} + T_{M.f}, \quad (2.12)$$

and cut finger diameter with the ribbon size b is

$$d_{f\,2} = \sqrt{d_{hole2}^{2} + b^{2} - (b + T_{M.hole} + T_{M.f} - S_{1\,max})^{2}}. \quad (2.13)$$

The workpiece shifts from its medium position in the directions perpendicular to the cylindrical finger axis are determined by minimum radial clearance S_1, base hole diameter tolerance T_{dhole1}, and finger diameter tolerance T_{df1}. The least shift equals S_1, and the greatest – $S = 0{,}5T_{dhole1} + 0{,}5T_{df1}$.

The shift values are used to determine the installation error for manufactured sizes. The greatest workpiece turn angle α from its nominal position may be calculated by the formula

$$\sin\alpha \approx \frac{1}{L}(S_1 + 0{,}5T_{dhole\,1} + 0{,}5T_{df\,1} + S + 0{,}5T_{dhole\,2} + 0{,}5T_{df\,2}), \quad (2.14)$$

wherein S is minimum radial clearance by cut finger seating fit (determined by the clearance on the hole common axis); T_{dhole2} is tolerance on the hole diameter for the cut finger; $T_{df\,2}$ is tolerance on the cut finger diameter.

Common holes' axis clearance equals

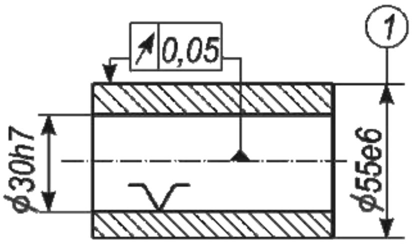
$$X = \sqrt{d_{hole2}^{2} - d_{f}^{2} + b^{2}} - b. \quad (2.15)$$

Installation fingers used for basing the workpieces by two holes and a plane are standardized. Cylindrical fingers' design is determined by ГОСТ 12209-66, and for the cut ones – ГОСТ 12210-66. Cylindrical ribbon width ***b*** depends on the cylindrical finger diameter, and for diameters of 4…6 mm it equals 1 mm, for diameters of 6…8 mm it is 2 mm, for 8…12 mm it is 3 mm, for 12…32 mm it is 4 mm, etc. The sizes of cylindrical finger depend on the workpiece mass. If the workpiece mass is up to 5 kg, the finger diameter doesn't exceed 6 mm, by 15 kg – 10 mm.

2.3 Examples of calculating the accuracy of workpieces' installation

Example 1. Calculate the precision of a mandrel for clean external turning of the workpiece external surface (Fig. 2.13). The analysis shows that the workpiece beating value doesn't exceed 0,05 mm, and it depends on the accuracy of its installation on the mandrel.

Let us check the beating tolerance $\boldsymbol{T \le 0{,}05}$ mm. The operational size error is made up of two components $\boldsymbol{\omega_{inst}}$ и $\boldsymbol{\omega_{machined}}$ (1.2) that are connected with machining method and installation.



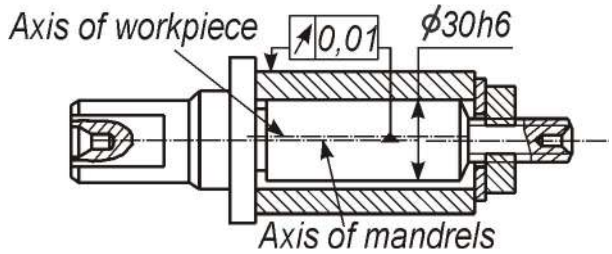


Figure 2.13 – On calculating the machining accuracy on the turning mandrel: a – operational draft; b – device

According to the formula (1.4), the installation error is made up of basing, fixation and device inaccuracy errors.

In the case viewed, the workpiece is installed on the mandrel by the hole $\varnothing\boldsymbol{30H7}$. The mandrel cylindrical surface diameter is $\varnothing\boldsymbol{30h6}$. The error connected with machining method $\boldsymbol{\omega_{machined}}$ is determined by technological system rigidity, temperature deformations, tool wear. In the viewed case $\boldsymbol{\omega_{machined}}$=0,01 mm [12].

Basing error $\boldsymbol{\omega_b}$ equals the greatest clearance between workpiece and mandrel diameters. Tolerance tables give us $\varnothing\boldsymbol{30H7} = \varnothing\boldsymbol{30^{+0{,}021}}$ mm, $\varnothing\boldsymbol{30h6} = \varnothing\boldsymbol{30_{-0{,}013}}$ mm, so

$\boldsymbol{\omega_b = S_{max} = ES + ei = 0{,}013 + 0{,}021 = 0{,}034}$ mm.

For the given fixation way $\boldsymbol{\omega_f = 0}$.

Device error ω_{dev} includes manufacturing ω_{man}, wear ω_{wear}, and device installation $\omega_{dev.inst.}$ errors.

In the given case, $\omega_{dev.inst.}$=0, as the mandrel in the centers is installed without errors, i.e. the mandrel center holes' axis doesn't shift relatively to the surface centers' axis.

Mandrel manufacturing error ω_{man} determines the mandrel bearing surface bearing relatively to its base surfaces (central nests). For the given case ω_{man}=0,01 mm.

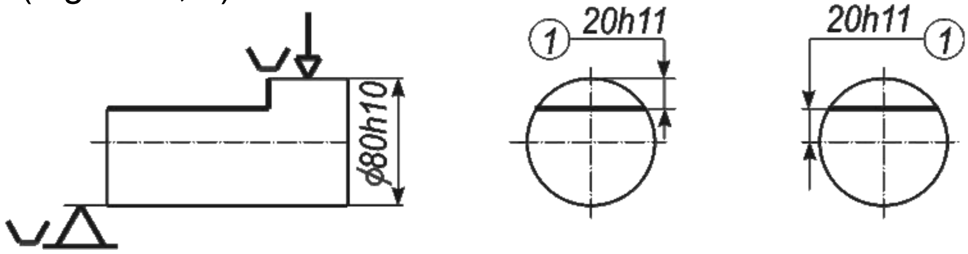
The device wear is specified in the device technical requirements, and wear error with regard to the mandrels doesn't exceed ω_{wear}=0,015 mm.

Let us calculate the resultant error using the formula (1.4)

$$\omega = 1{,}2\sqrt{0{,}01^2 + 0{,}034^2 + 0{,}001^2 + 0{,}015^2} = 0{,}048 \text{ mm.}$$

This way, the mandrel provides the required accuracy.

Example 2. Calculate the accuracy of the flats milling device in a cylindrical workpiece that is based and fixed on a prism with the angle $\alpha = 90^o$ (Fig. 2.14, a).



a b c

Figure 2.14 – On calculating the machining accuracy by milling with installation on a prism

Tolerance on the size ***20h11*** makes up $T = 0{,}13$ mm. The constructional base for the flat is the upper point of diametral axis (Fig. 2.14, b).

Machining error $\omega_{machining}$ is determined in the first place by rigidity and technological system deformation under the cutting forces. For the given case let us take $\omega_{machining}$=0,02 mm [12].

Basing error ω_b of a cylindrical workpiece in the prism with the angle $\alpha = 90^o$ is determined by the formula (2.7).

The tolerance on the size ***80h10*** equals ***0,12*** mm [12], then

$$\omega_b = \frac{0{,}12}{2}\left(\frac{1}{\sin 45^o} + 1\right) = 0{,}177 \text{ mm.}$$

For the given case, fixation error ω_f =0. The prism installation error doesn't exceed $\omega_{pris\ min\ st.}$ =0,02 mm [12].

Let us determine the resultant error by the formula (1.4)

$$\omega = 1{,}2\sqrt{0{,}02^2 + 0{,}177^2 + 0{,}02^2} = 0{,}21 \text{ mm.}$$

The designed device doesn't provide the required accuracy, as $\omega = 0{,}21 > T = 0{,}13$ mm.

In order not to complicate the device construction, it is reasonable to change the type of putting operational size from the cylindrical surface axis (Fig. 2.14, c). Then, the workpiece basing error into the prism is determined according to the formula (2.8).

By other equal conditions, the resultant error is calculated according to the formula (1.4)

$$\omega = 1{,}2\sqrt{0{,}02^2 + 0{,}092^2 + 0{,}02^2} = 0{,}11 \text{ mm.}$$

With such manufacturing size setting, the device provides the given accuracy.

Example 3. Calculate the machining accuracy of the hole *Ø10H8* in a workpiece in the jig with fast-change bushing (Fig. 2.15). The workpiece is based with its plane on the bearing surfaces, and with its hole *Ø12H8* – on the rhombic finger.

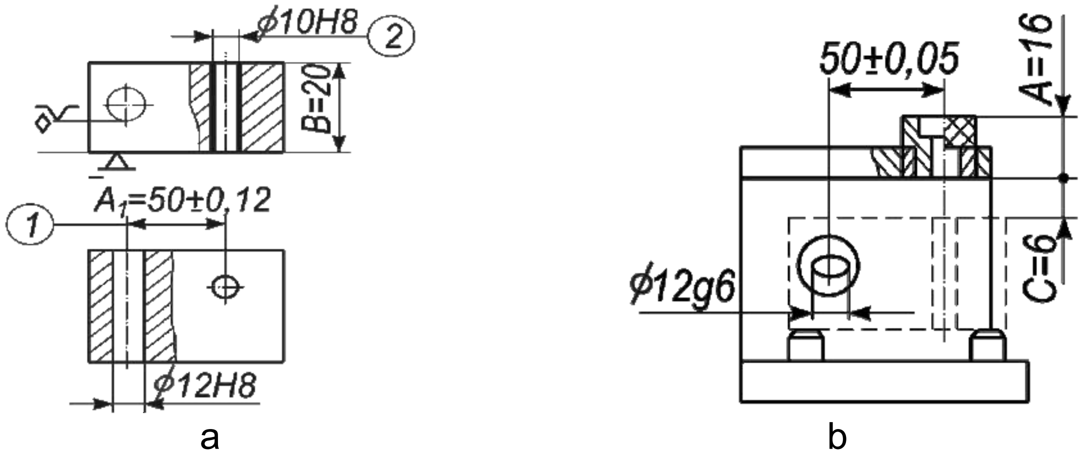


Figure 2.15 – On calculating the accuracy of machining the hole in the jig: a – operational draft; b – jig

Operational draft shows that by carrying out the operation the hole sizes are kept *Ø10H8* and $A_1 = 50 \pm 0{,}12$ mm. The analysis shows that the size *Ø10H8* is received with the cutting tool, and the manufactured size A_1, the tolerance of which $T = 0{,}24$ mm depends on the machining accuracy in the jig.

Machining error for the given method is small, l et us take

$\omega_{machining} = 0$.

Jig installation error by drilling $\omega_{inst.dril} = 0$, as the coordinates of the hole machined do not depend from the position of the jig frame on the machine table. The device error depends on the workpiece basing error and directional elements' errors.

Workpiece basing error ω_b equals to maximum clearance between the workpiece hole and rhombic finger diameter. For the sizes with seating fits Ø$12H8$ $(+0{,}027)$ mm, Ø$12g6$ $\left({}^{-0{,}006}_{-0{,}017}\right)$ mm

$$\omega_b = S_{max} = ES + ei = 0{,}027 + 0{,}017 = 0{,}044 \text{ mm.}$$

Directional elements error depends on axis shift error relatively to the ω_{shift} nominal position and hole axis drift error [12]

$$\omega_{shift} = \sqrt{T_A^2 + e_c^2 + S_{bushing}^2 / 4 + e_{bushing}^2}. \tag{2.16}$$

Axis shift error relatively to its nominal position [12]

$$\omega_{shift} = \sqrt{T_A^2 + e_c^2 + S_{bushing}^2 / 4 + e_{bushing}^2}.$$

Let us determine hole axis drift error by the formula [12], analogically to the formula (1.5):

$$\omega_{drift} = S_{max}\left(\frac{B + C}{A} + \frac{1}{2}\right). \tag{2.17}$$

Fig. 2.15 shows that the tolerance on one-sided size shift from the resting element to the axis equals $T = 0{,}06$ mm, constant bushing eccentricity $e_c = 0{,}01$ mm, snap-change bushing eccentricity – $e_{bushing} = 0{,}01$ mm. Snap-change bushings are installed into constant bushings by seating fits $H7/g6$. For the drill of Ø10 mm fast-change bushing has the external diameter Ø$15g6$ mm. The sizes with seating fits Ø$15H7$ $(+0{,}018)$ mm, Ø$15g6$ $\left({}^{-0{,}006}_{-0{,}017}\right)$ mm have maximum clearance between the bushings $S_{bushing} = ES + ei = 0{,}018 + 0{,}017 = 0{,}035$ mm. Let us calculate the axis shift error relatively to the nominal position according to the formula (2.15):

$$\omega_{shift} = \sqrt{0{,}06^2 + 0{,}01^2 + 0{,}035^2 / 4 + 0{,}01^2} = 0{,}1 \text{ mm.}$$

In order to get the hole Ø$10H8$, in the technological process the workpiece is drilled up to Ø$9{,}8H11$ with its further reaming to Ø$10H8$. The drilling is done with the drill Ø$9{,}8_{-0{,}036}$ mm. The hole diameter in the snap-change bushing is Ø$9{,}8F7$ $\left({}^{+0{,}028}_{+0{,}013}\right)$ mm. Then maximum clearance between the bushing and the drill

$$S_{max} = ES + ei = 0{,}036 + 0{,}028 = 0{,}064 \text{ mm.}$$

Let us determine the axis hole drift error in the workpiece using the dimensions of the constructed jig by the formula (2.16):

$$\omega_{drift} = 0{,}064\left(\frac{20+6}{16} + \frac{1}{2}\right) = 0{,}136 \text{ mm.}$$

Let us determine the operational size resultant error

$$\omega = 1{,}2\sqrt{\omega_b^2 + \omega_{shift}^2 + \omega_{drift}^2} = 1{,}2\sqrt{0{,}044^2 + 0{,}1^2 + 0{,}136^2} = 0{,}216 .$$

The designed jig provides the required accuracy, as $\omega = 0{,}216 < T = 0{,}24$ mm.

3 CLAMPING ACCESSORIES OF MACHINE RETAINING DEVICES

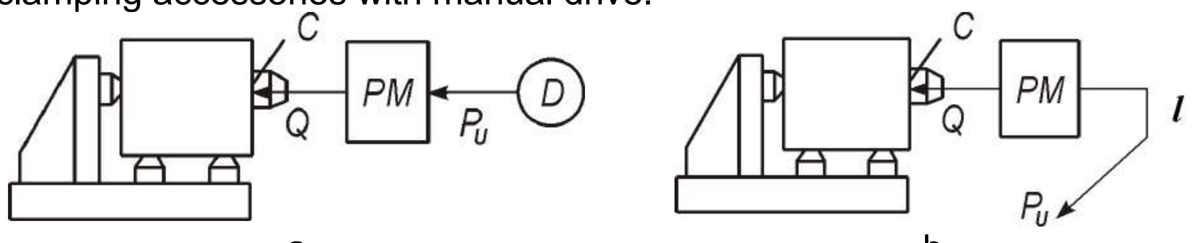
3.1 Purposes and specifications of clamping accessories

Clamping elements (clamps) are used for providing contact of the workpiece with location pieces and providing its reliable fixation in the process of machining. In this way, the workpiece gets higher rigidity and vibration stability, which allows machining with the given accuracy and efficiency.

All devices' clamping accessories may be divided into three groups [3, 6, 14].

To the first group (Fig. 3.1, a) belong clamping accessories that include power mechanism (PM), and drive (D) that creates initial force P_i; it is transformed by power mechanism into holding force Q and provides contact element (C) shift. Drives used in such conditions are rather varied: pneumatic, hydraulic, pneumohydraulic, mechanical, etc.

The second group (Fig. 3.1, b) includes clamping accessories that consist only of power mechanism that is actuated directly by the worker who applies initial force P_i on the arm l. These devices are called clamping accessories with manual drive.



a b

Figure 3.1 – Schemes of clamping devices

The third group includes clamping accessories that do not have power mechanism, and the drives used do not cause shifts of clamping accessory's elements and create only holding force $\boldsymbol{Q}$. The force $\boldsymbol{Q}$ in these conditions is uniformly distributed load resultant that acts directly on the workpiece; it is created as the result of atmospheric pressure (when there is vacuum on the opposite side of the workpiece), or by means of magnetic power flow. To this group belong vacuum and magnetic accessories.

Clamping accessories should satisfy the following demands:

- by fixing, the workpiece position reached by its basing mustn't change;
- fixing must be reliable, so that the workpiece position doesn't change while machining;
- workpiece surface crumpling that appears by fixing, and also deformation must be minimal and stay within permissible limits;
- even workpiece fixation must be provided, especially in multipiece devices;
- device fixing and unfixing must be carried out with minimum force and time waste;
- accessories must be reliable in operation, easy in design, convenient and safe in maintenance.

If these fixing rules are not fulfilled, machining inaccuracies may occur, and changing the workpiece position during cutting may cause disruption of the cutting tool.

The demands that are put forth to the devices' clamping accessories are fulfilled by rational choice of fixation scheme and value of holding force $\boldsymbol{Q}$. The workpiece fixation scheme is chosen simultaneously with designing its way of basing, the result of which is determining the place of application and direction of fixation force.

When doing so, the following should be taken into consideration:

- for reducing the holding force by workpiece fixing, it is necessary to choose such way of basing, by which the cutting force is directed on a bearing element on this force's line of action or close to it;
- for providing contact of the workpiece with the bearing element and elimination of its possible shift while fixing it, the holding force should be directed perpendicularly to the bearing element surface. In separate cases the holding force may be directed in such a way that the workpiece is pressed to the surfaces of two bearing elements at the same time;
- for reducing the workpiece surface crumpling while fixing it, it is necessary to reduce the pressure in the places of contact of the clamping device and the workpiece by spreading the holding force. This is reached by using the contact elements of the required construction in the clamping accessories – they help to spread the holding force uniformly between

two or three points, sometimes even on an extensive surface, and also by installing the supports that take excessive cutting forces that aren't absorbed by friction;

– for reducing workpiece vibrations and deformations under the impact of cutting force, the rigidity of the workpiece – device system should be increased; this is reached by increasing the number of the workpiece clamped surfaces and situating them closer to the machined surface.

3.2 Determining the holding forces by installing the clamping accessories in different ways

Cutting forces are variable by their value, direction and point of application. By tool digging, the cutting forces increase from zero up to maximum and decrease from maximum down to zero (tool leaving). In this set mode, the cutting force vibration amplitude reaches 10% of its nominal value. The cutting force point of application during machining continuously moves along the machined surface, that is why the cutting force is not of static, but of dynamic character. By discontinuous surface machining, cutting dynamics increases ever more. With tool dulling, cutting forces get a 10…30% increase and more [5, 8].

Volume forces – mass, centrifugal, and accelerative – appear by certain machining conditions. Workpiece gravity forces act and are taken into consideration when the workpiece is installed on vertical or inclined elements. During machining by cutting, the workpiece mass continuously decreases, and the position of its centre of gravity changes.

Centrifugal forces appear in during machining process when the workpiece center of gravity shifts relatively to its turning axis. The values of centrifugal forces and moments of forces that act on the workpiece by dynamic misbalance are comparable with the values of cutting forces and moments of forces by finish machining.

Accelerative forces (moments) appear when the workpiece is in reciprocating motion or it turns with great angular accelerations (for example, by spindle slowdown). Usually these forces and moments of forces are little comparably to cutting forces and moments of forces.

Cutting force direction and point of application change when the tool is moved along machined surface, and when machining conditions change. The cutting forces and moments that they create influence the workpiece: they tend to turn the workpiece relatively to the device location pieces, move the workpiece from the set position in the device, or pull it out of the clamping accessory. Nevertheless, the workpiece must keep its position during the machining process relatively to the device bearing elements.

The forces and moments of forces that act on the workpiece are determined by standards and metal cutting theory formulas with regard to a certain machining type.

In the process of machining, the actual cutting forces may significantly differ from the calculated ones as a result of variation of mechanical properties of the material itself, cold working and workpiece peel; cutting tool dulling, removed allowance unevenness, etc. Besides, by set holding force calculation scheme, various contact conditions are possible (surfaces crumpling, presence of lubricant, different roughness, etc.) between device bearing surfaces and the workpiece, workpiece and clamp.

All these changes of cutting forces and contact conditions are impossible to be considered by calculating. That is why in practical calculations the calculated cutting force value is multiplied by fixation safety factor $\boldsymbol{K}$.

In order for the workpiece not to turn relatively to the device installation elements during machining, the following is taken:

$$\boldsymbol{M_{hold} = KM_{cut}}, \tag{3.1}$$

wherein $\boldsymbol{M_{hold}}$ is holding force moment; $\boldsymbol{M_{cut}}$ is cutting force moment.

In order for the workpiece not to move from the set position during machining, the following is taken:

$$\boldsymbol{Qf = KP_o}, \tag{3.2}$$

wherein $\boldsymbol{Q}$ is clamping force; $\boldsymbol{f}$ is friction coefficient; $\boldsymbol{P_o}$ is cutting force that causes axial movement or workpiece shift.

In order for the workpiece not to be pulled out of the clamping accessory, the following is taken:

$$\boldsymbol{M_{hold} = KM_{pull}}, \tag{3.3}$$

wherein $\boldsymbol{M_{pull}}$ is cutting force moment that causes workpiece pulling or overthrow.

The value of fixation reliability coefficient $\boldsymbol{K}$ should be chosen differentially depending on certain conditions of operation fulfillment and the way of workpiece fixation. For rough stages of machining it is recommended to take $\boldsymbol{K = 2,0...2,5}$; for finishing and workpiece nonferrous metal machining $\boldsymbol{K = 1,3...1,5}$.

The required clamping force value is determined by solving the task of statics – considering the workpiece balance under the action of forces applied to it. To do so, it is necessary to make the analytical model, i.e. to show on the workpiece basing scheme all forces that act on it: cutting forces and moments, clamping forces, bearings' reaction and friction forces in the contact places of the workpiece with bearing elements and clamping accessories. The analytical model should be made for the most unfavorable cutting tool position on the machined surface.

The analytical model is used then for setting the possible workpiece move or turn under the impact of cutting forces and moments; determining projection values of all forces on the shift direction; and for writing the equations of forces and moments.

Basing upon solving statics equations solving, we get the formulas for calculating the holding force $\boldsymbol{Q}$ that provides reliable workpiece fixation. Let us illustrate this with examples.

Example 1. When performing milling on a plane (Fig. 3.2) with the set way of basing and fixation scheme of a workpiece with the length $\boldsymbol{l}$, the workpiece may turn relatively to the point $\boldsymbol{O}$ under the impact of cutting forces and shift in the axial direction.

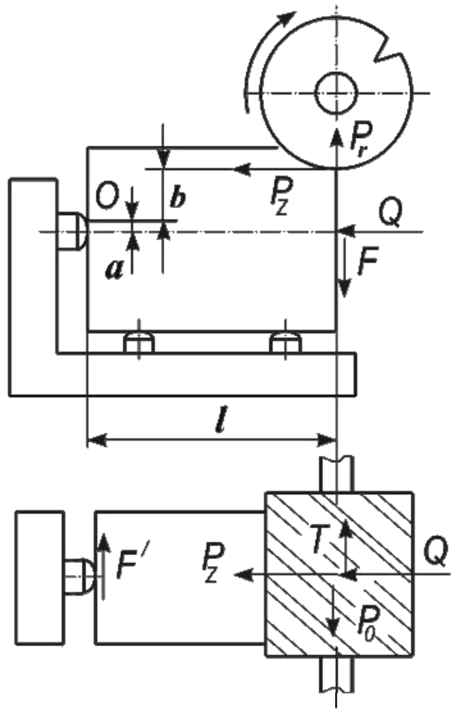


Figure 3.2 – Scheme that illustrates determining the clamping force value by milling

From the condition of the workpiece balance, the equation of the moments looks as follows:

$$\boldsymbol{Qa + Fl = P_z b + P_r l},$$

wherein $\boldsymbol{P_z}$, $\boldsymbol{P_r}$ are cutting forces, $\boldsymbol{F}$ is friction force; $\boldsymbol{F = fQ}$.

After introducing the reliability coefficient $\boldsymbol{K}$, the equation looks as follows:

$$\boldsymbol{Qa + fQl = K(P_z b + P_r l)},$$

whence

$$Q = \frac{K(P_z b + P_r l)}{a + fl},$$

wherein f is friction coefficient between the workpiece and clamping accessories.

Axial force P_o tends to shift the workpiece. Friction forces between the workpiece and bearing elements (F') and between the workpiece and clamping accessories (F) will hold the workpiece in the accessory. The equation of forces, considering the fixation reliability coefficient, looks as follows:

$$Qf + Qf' = KP_o,$$

whence

$$Q = \frac{KP}{f + f'}$$

wherein f' is friction coefficient between the workpiece and device bearing elements.

Example 2. Fig. 3.3 shows drilling a hole in a workpiece fixed in a three-jaw chuck. The workpiece may shift along the jaws under the action of cutting force P_o and turn in the jaws under the action of the cutting moment M.

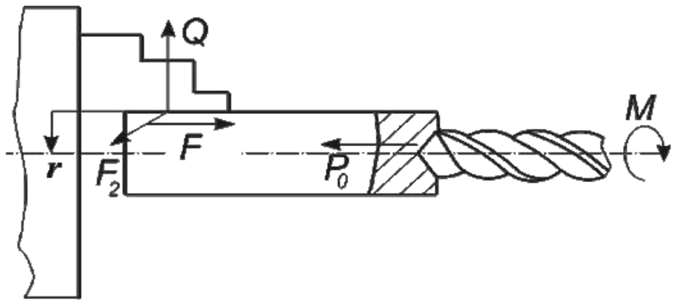


Figure 3.3 – Scheme that illustrates determining the clamping force by drilling a hole in a workpiece on a turning machine

It is necessary to apply such clamping force, so that the workpiece doesn't shift or turn relatively to the jaws. Depending on the jaw knurl, the shift and turn resistance may be different, as friction coefficients may also be different.

Let us assume that then the workpiece shifts on the jaws along the axis, friction coefficient is f_1 and by turning it is f_2.

Friction forces between the jaw and the workpiece by shift are $F_1 = f_1 Q$, and by turning they are $F_2 = f_2 Q$.

Let us determine the clamping force under the condition that the workpiece shift in the jaw is not permitted. Using accepted designation and considering that the chuck has three jaws, let us make up the equation of forces: $3F_1 = P_o$. After substituting the value of F_1 and introducing the coefficient K, the equation will look as follows:

$$3f_1Q = KP_o,$$

whence

$$Q = \frac{KP_o}{3f_1}.$$

Now let us determine the clamping force under the condition that the workpiece turn in the jaw is not permitted. As the workpiece is fixer in three jaws, the equation of the moment of forces will look as follows:

$$3F_2r = M,$$

wherein r is external cylindrical surface radius of the workpiece on the area of its fixing in the jaws. After substituting the value of F_2 and and introducing the coefficient K, the equation will look as follows:

$$3f_2Qr = KM,$$

whence

$$Q = \frac{KM}{3f_2r}.$$

Out of these two fixation forces the greatest one is chosen.

Example 3. When drilling, the workpiece is installed in the prism (Fig. 3.4). There the workpiece is under the action of the moment M and axial force P_o.

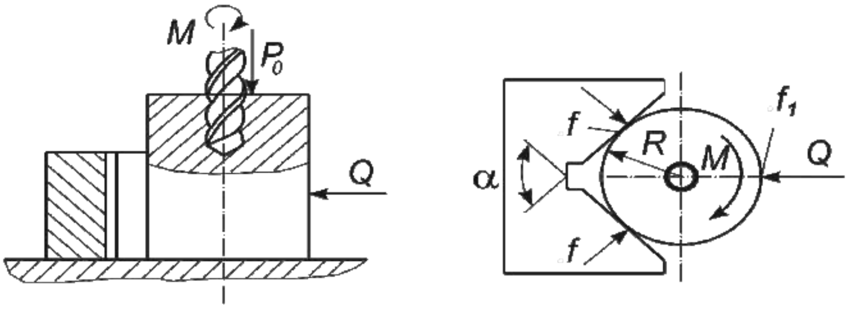


Figure 3.4 – Scheme that illustrates determining the clamping force in a prism by drilling a hole in a workpiece

The workpiece may turn under the action of the moment of forces. Let us write the workpiece balance equation as follows (not considering friction on the end):

$$f_1RQ + F_2Q\frac{1}{sin(\alpha/2)} = KM,$$

whence

$$Q = \frac{KM}{f_1R + f_2R/sin(\alpha/2)}.$$

If the workpiece shifts under the action of the axial force $\boldsymbol{P_o}$ along the prism,

$$Q = \frac{KP_o}{f_1' + f_2' / \sin(\alpha/2)}.$$

Example 4. By milling a chase (Fig. 3.5), the workpiece is installed on the plane and fixed with two clamp arms.

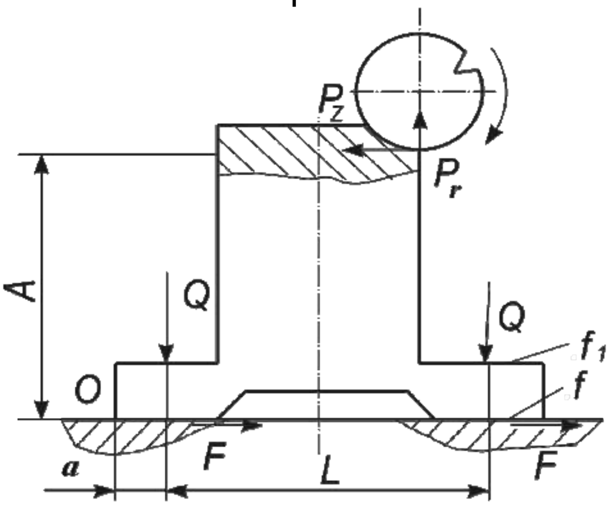


Figure 3.4 – Scheme that illustrates determining the clamping force in a prism by milling a chase

Cutting force $\boldsymbol{P_z}$ that appears during machining tends to move the workpiece and tear it off the bearing. There, the workpiece will turn relatively to the point $\boldsymbol{O}$. Friction forces that appear between the bearing and the workpiece, and also between the clamp arms and the workpiece, will prevent it from shift. The equation of forces may be written as follows:

$$Qfn + Qf_1 n = P_z.$$

After introducing the reliability coefficient $\boldsymbol{K}$,

$$Qn(f + f_1) = KP_z,$$

whence

$$Q = \frac{KP_z}{n(f + f_1)},$$

wherein n is the number of clamp arms; $\boldsymbol{f}$ is friction coefficient by the workpiece shift relatively to the bearing; $\boldsymbol{f_1}$ is friction coefficient by the workpiece shift relatively to the bearing clamp arm.

The moment of forces' equation relatively to the point $\boldsymbol{O}$ will look as follows:

$$Qa + Q(a + L) = K(P_z A + P_r (L - a)),$$

wherein $\boldsymbol{a}$ is the distance between the point $\boldsymbol{O}$ and the point of force application $\boldsymbol{Q}$; $\boldsymbol{L}$ is the distance between clamp arms; $\boldsymbol{A}$ is operational dimension.

Finally, we have

$$Q = \frac{K(P_z A + P_r (L - a))}{2a + L}.$$

In the devices, friction forces appear on the surfaces of the workpiece contact with bearing elements, and also in the places of contact of clamping devices and with the workpiece surface. The value of friction coefficient depends on many factors. In many cases, the devices have interacting surfaces with knurling of various form and directivity. By fixation, the knurling teeth are pressed into the body of the workpiece treated, and the pressing value depends on normal reaction force in the places of contact. Strictly speaking, the forces that appear on such surfaces and that prevent the workpiece from turning or shifting may not be called friction forces. It is more correct to call them shift resistance forces. But in order to make things more simple and short, let us use the term "friction coefficient" and denote it f furthermore.

In the devices, there may be many various combinations of contact surfaces that vary in their form, surface conditions, rigidity, etc. The values of friction coefficient for some combinations of contact surfaces are given in Table 3.1 [12].

Table 3.1 – Values of friction coefficient

Contact surface characteristics	Value of f
The workpiece treated surface contacts with the bearing surfaces plane or the plane of contact elements of clamping devices	***0,10...0,15***
The workpiece treated surface contacts with the bearing element on the line (basing on a prism) or sphere (basing on a bearing plug with a spherical head)	***0,18...0,30***
The workpiece surface that is not yet treated with a flat bearing element	***0,5...0,8***
A contact element touches the workpiece cylindrical surface while it is fixed (by installing in the jaws, chuck collet, etc.) and has:	
– smooth surface,	***0,25***
– annular grooves,	***0,35***
– cross grooves	***0,45***
By fixing, the contact element touches the workpiece surface that is not yet treated and has:	
– annular grooves,	***0,4...0,5***
– knurling	***0,5...0,8***

After determining the clamping force value $\boldsymbol{Q}$, the constructor chooses the type of clamping device. In the process, the clamping force value, the workpiece sizes and configuration, the character of the operation performed, production type are considered. For the chosen power mechanism, the initial effort $\boldsymbol{P_u}$ should be determined; it will provide creating the required clamping effort $\boldsymbol{Q}$.

When choosing a manual power mechanism, it is necessary to take into consideration that the worker applies force of not more than $\boldsymbol{P_u = 150\ N}$ to the handle or driving tool.

Currently, many schemes and designs of power mechanisms were worked through and tested. Many of them are normalized, and the designer may choose the machine arrangement that most fully suits certain working conditions of the designed device.

3.3 Schemes of simple clamping accessories

The devices' clamping mechanisms may be simple and combined.

The clamps are called ***simple*** if the force that comes from the source is passed to a workpiece fixed directly through one segment. They include screw pair, wedge, eccentric, spring. ***Combined*** clamps consist of sequentially interconnected several simple clamps. By the number of the points of fixation force application, clamping devices may be singular or multiple [1, 9].

Multiple clamping devices fix one workpiece in several points or several workpieces simultaneously using the same force.

Screw clamps are widely used, their design is simple, and they allow to create great fixation force. Its sufficient drawback is that great additional time is required for fixing. Fixing is carried out by means of a screw or a nut.

Direct impact of the screw end on the workpiece causes surface crumpling, and thus is allowed only by fixing the non-machined or raw-machined workpieces. Clamping screws are made of 45-steel with the head and working end hardening up to $HRC\ 35..40$.

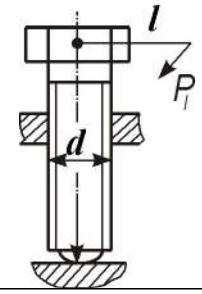
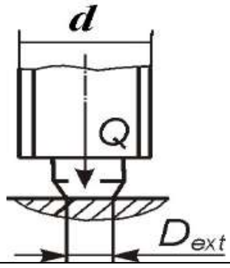
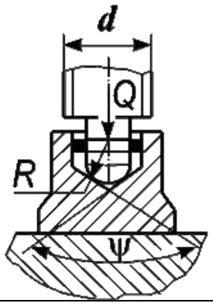
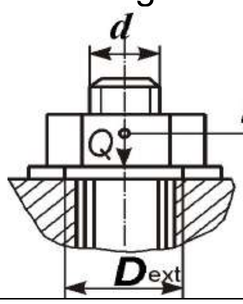
In the cases when it is inadmissible to have compression marks on the fixed workpiece surface, reference anvils are used.

Reference anvil is fixed to the fixation screw working end on hinges, and it allows to pass the push on a large surface, thus reducing the specific pressure. Hinge fixation of the anvil keeps the fixation screw from bending even if the workpiece clamping surface is inclined.

Nuts are used when the workpiece is fixed by hole basing. Device clamping nuts go with split-type (fast-change) washers that allow to install and remove the workpiece by little unscrew of the nut.

Table 3.2 gives design formulas for determining the clamping force by using screw mechanisms.

Table 3.2 - Design formulas for determining the clamping force by using screw mechanisms

Mechanism design	Design formulas
Sphere-end screw 	$P_i \approx \frac{d}{10l} Q$
Flat-end screw 	$P_i \approx \frac{0,1d + 0,05D_{ext}}{l} Q$
Chair screw 	$P_i \approx \frac{0,1d + 0,15Rctg\frac{\psi}{2}}{l} Q$
Using a nut 	$P_i \approx \frac{0,1d + 0,05\frac{D_{ext}^3 - d^3}{D_{ext}^2 - d^2}}{l} Q$

Note. Q – clamping force; P_i – initial force; l – arm, to which the initial force is applied; D_{ext} – external diameter of a screw or nut bearing end; D_{int} – internal diameter of a screw or nut bearing end; R – screw end radius; ψ – angle of chair bearing surface.

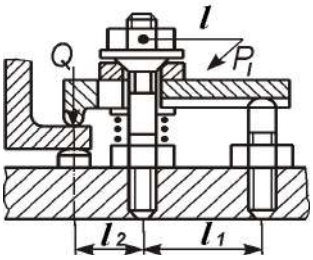
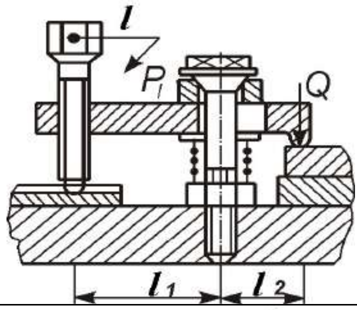
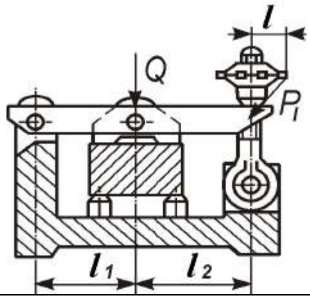
3.4 Schemes of combined clamping accessories

Combined clamping devices that consist of a lever combined with screw, eccentric or wedge mechanisms are called ***clamp arms***.

Clamp arms are used for increasing the fixation forces, changing the clamping element running, changing the direction of clamping forces, reducing the overall size of a clamping device in the places of its contact with the workpiece.

Table 3.4 gives design formulas for determining the clamping force of the most typical combined power forces – clamp arms.

Table 3.4 – Design formulas for determining the clamping force of clamp arms

Mechanism design	Design formulas
	$P_i = \dfrac{r_m tg(\alpha+\varphi_{eff}) + \dfrac{1}{3} f \dfrac{D_{ext}^3 - d^3}{D_{ext}^2 - d^2}}{l} \times \dfrac{l_1 + l_2}{l_1 \eta} Q$
	$P_i = \dfrac{r_m tg(\alpha+\varphi_{eff})}{l} \dfrac{l_2}{l_1 \eta} Q$
	$P_i = \dfrac{r_m tg(\alpha+\varphi_{eff}) + \dfrac{1}{3} f \dfrac{D_{ext}^3 - d^3}{D_{ext}^2 - d^2}}{l} \times \dfrac{l_1}{(l_1 + l_2)\eta} Q$

<u>Note.</u> Q – clamping force; P_i – initial force; $2r_m$ – screw thread medium diameter; α – angle of screw thread rising (for metrical thread $\alpha = 2^o 30'$); d – screw thread diameter; φ_{eff} – effective friction angle in the thread ($\varphi_{eff} = 10^o 30'$); f – friction coefficient between the bearing end and the workpiece; D_{ext} – external diameter of a screw or nut bearing end; D_{int} – internal diameter of a screw or nut bearing end; l – arm, to which the initial force is applied; l_1, l_2 – lever arms; η – coefficient that considers losses on friction in the lever base ($\eta = 0,85$).

4 DIRECTIONAL ELEMENTS OF MACHINE RETAINING DEVICES

4.1 Purposes of directional elements

Directional elements that are used in the devices serve for directing and coordinating the tool and may perform different functions.

The first group of elements allows preventing the tool run during machining. For this, the bushings that direct the front part of the knee-type carrier by deep hole boring are used.

The second group of elements simultaneously carries out two functions: they direct the tool along the given line (i.e. prevent the tool run) and provides the required position of the tool relatively to the device. Such elements include aligning bushings that are used in drilling and boring devices.

The third group of elements serves for providing the required position of the tool relatively to the device. Such elements include setting blocks that help to set up the machine for a given size. Setting the machine with the help of setting blocks takes less time than the method of calibrating cut, that is why it is widely used by workpiece machining.

4.2 Design of aligning bushings

Aligning bushings are used for determining the position and direction of various axial instruments by treating the holes – drills, core drills, reamer bits, etc. They determine the position of the instrument axis relatively to the device installation elements and increase its radial rigidity. Thus, there is no need in laying out the treated workpieces, and this, in its turn, increases the accuracy of the hole position and labor productivity. Increasing the tool rigidity leads to increasing the accuracy of hole diameter, reducing the tool run, allows working on higher cutting regimes. According to the data given in the works [7, 10], the hole diameter accuracy rises on the average on ***50%*** in comparison to the accuracy by machining without aligning bushings.

The devices equipped with aligning bushings and used for machining the holes on the machines of drilling series are called ***jigs.***

There are three types of standard aligning bushings: stationary, changeable and quick-change (Fig. 4.1).

Stationary bushings are made without collar according to ГОСТ 18429-73 (Fig. 4.1, a) and with collar according to ГОСТ 18430- 73 (Fig. 4.1, b). They are used when the hole is machined with only one tool (drill or core drill). During its installation in the bush plate, they are pressed by the ***H7 / n6*** seating fit.

Changeable bushings are made according to ГОСТ 18431-73 (Fig. 4.1, c). Alike stationary bushings, they are used by machining the holes with one instrument, but in those cases when it is necessary to change the tool fairly often because of its wear. Changeable bushings 2 are installed into the intermediate bushings 3 by the ***H6 / g5*** or ***H7 / g6*** seating fit, and to avoid turn and lift by machining, they are fixed with the screws 1. Intermediate bushings 3 are pressed into the bushing plate by the ***H7 / n6*** seating fit.

Quick-change bushings are made according to ГОСТ 18432-73 (Fig. 4.1, d). Alike changeable bushings, they are installed into the intermediate bushings by the ***H6 / g6*** or $H7/g6$ seating fit. They are used in the cases when during operation the hole is machined consequently with several instruments, for example, with the drill, core drill and reamer bit. For directing each of them, their own quick-change bushing is provided. All bushings have the same external diameter, and internal ones have the diameter of the corresponding instrument. The bushings' collar is made high, and with the knurl, for their convenient holding by installation and removal. The collar has through longitudinal shear that allows easy inserting and removing the bushing by changing, and also there is site ledge for its fixing with the help of a bar that prevents the bushing from its extrusion with cutting chips. By removing, the bushing is turned counterclockwise, until the shear coincides with the bar, and pulled up.

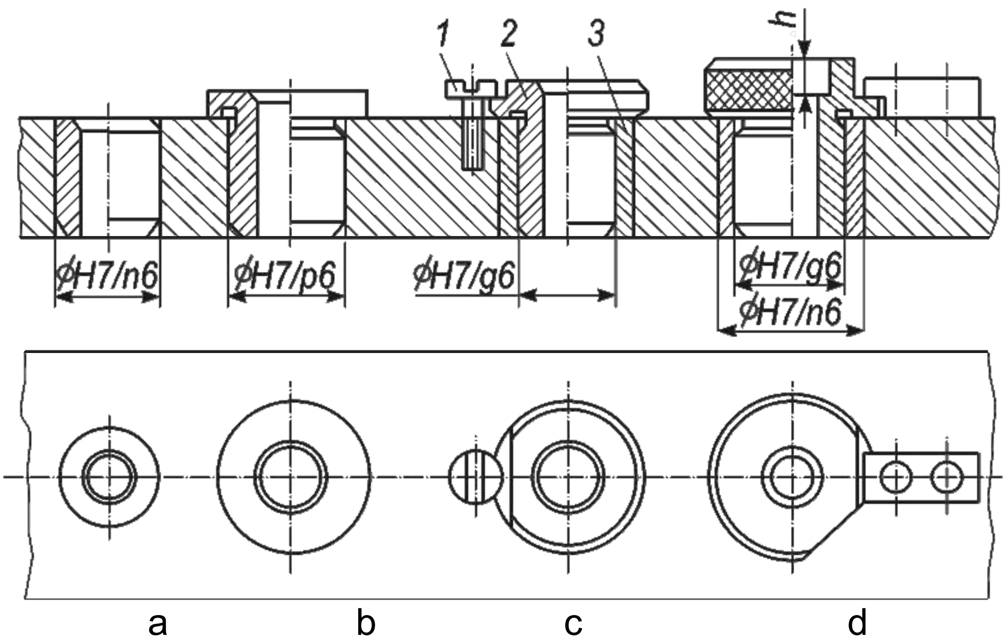


Figure 4.1 – Standard aligning bushings: a – stationary bushing without collar; b – stationary bushing with the collar; c – changeable bushing; d – fast-change bushing

Cutting tool is directed to the holes of all aligning bushings by movable clearance fit. The tool is taken as basic shaft (the hole in the bushings is made in the shaft system), and the necessary clearance fit is provided by the hole diameter. Clearance fits ***G7*** or ***F8*** are used for directing drills and core drills, and ***G7*** is used for reamer bits.

Stationary, changeable and fast-change bushings are of two versions: without the inner diameter neck (see Fig. 4.1, a, b, c), and with the inner diameter neck (see Fig. 4.1, d) that makes it easier for the tool to get into the bushing. The height of stationary and changeable bushings is ***1,5...2*** of the diameter of the bushing hole for the tool. The height of fast-change bushings is slightly greater, but they have a cave of ***h*** depth (see Fig. 4.1, d), because of which the contact length of the tool with the bushing remains the same as in stationary bushings.

All aligning bushings with the hole diameter up to ***25*** mm are made of У10А, У12А steel and hardened up to HRC 62…65. Intermediate bushings with the hole diameter up to *25* mm are made of У7А steel and hardened up to **HRC 45…50**.

The distance from the lower end of the bushing to the workpiece surface equals to ***0,3...1*** of the hole diameter.

Special bushings are designed according to the workpiece and operation peculiarities. The sitting fit of a tool in the bushing, its height, the distance between the bushing and the workpiece remain the same as for the standard ones.

5 FRAMES OF MACHINE RETAINING DEVICES

5.1 Purposes, design and material of the frames

Frame is the main part of the device, on which all other elements are set and fixed in a strictly determined order, thus forming a single construction. The frame has base mounting surfaces for its orientation and its fixation to the machine.

The device frame takes all the forces that are applied to the workpiece while it is installed and machined, that is why it should have sufficient hardness, rigidity, and vibration resistance.

When designing the frames, besides hardness, rigidity, and vibration resistance, it is necessary to provide other demands, such as:

- stability of the frame during its maintenance, i.e. the frame shouldn't wear much during work, and it shouldn't change its geometrical parameters through permanent deformation and buckling;
- quickness and accuracy of installation and joining the device frame and the machine; removing the cutting chips; and also compliance with all the labour protection rules.

The design of the frames varies a lot. Form and shape of the frames depend on the workpiece size and configuration, type of operation, number of workpieces simultaneously installed into the device, type of machine for which it is designed.

The frames of complicated forms are made of iron СЧ15-32 workpieces cast according to individual models, heavy-duty frames – of 35Л or 45Л steel and light-load frames – of АЛ-9 alloy.

The frames of medium form are made of welded workpieces. In this case, the terms of frame manufacturing, mass and cost are less in comparison to those of a cast frame.

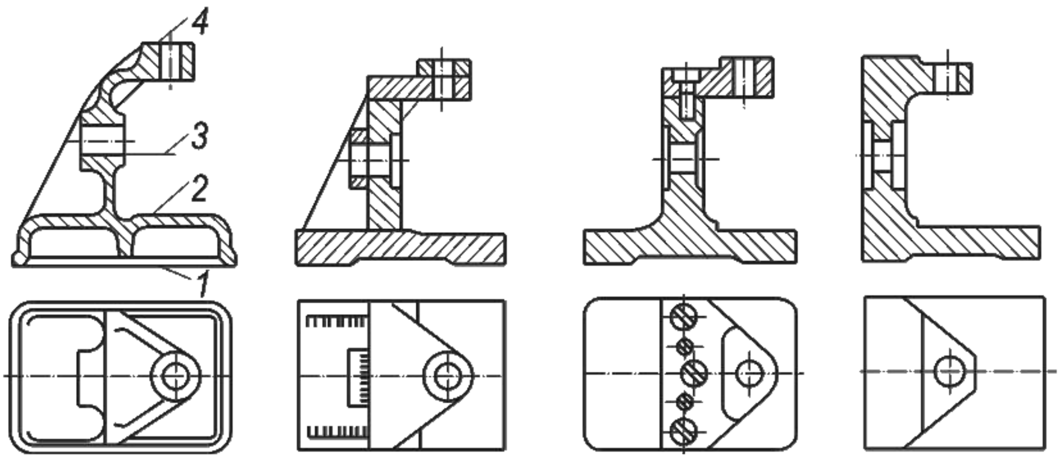
The frames of less complicated forms and increased hardness are manufactured from the forged workpieces.

The frames of simple forms are made assembled from separate parts made of 45 steel. The frame parts are made of rolled metal, machined and joined with the help of pins and screws.

The frames manufactured from cast, forged and welded workpieces should get heat treatment to relieve internal residual voltage.

When constructing the frames, it is recommended to use standard workpieces and frames. This allows reducing the expenditures and terms of the device production.

Let us consider the typical example of how the way of frame manufacturing impacts the jig frame embodiment (Fig. 5.1). Plane 1 of the frame serves as basing surface, surfaces 2 and 3 are for location and clamping elements, and hole 4 is for aligning bushing.



a b c d

Figure 5.1 – Variants of jig frame design
when it is made of different workpiece types

Fig. 5.1, a, shows the variant of a cast frame. In order to reduce machining, the treated surfaces rise above the rough surfaces that adjoin them. There is also webbing that improve the frame strength and rigidity.

The variant of the frame shown in Fig. 5.1, b, is made of a welded workpiece. Here, the webbing is also provided. The treated surfaces are placed at different levels, with the rough surfaces adjoining them.

The assembled frame (Fig. 5.1, c) consists of two parts: standard T-shaped cast workpiece and a special bar. The parts that are joined together are fixed with two pins and screwed. For designing assembled frames, normalized or standard workpieces are used. Fig. 5.1, d, shows the frame fully made of a standard cast workpiece.

Using of one or another way of frame manufacturing is determined by the cost of the frame when different ways of its realization. In practice, cast and assembled frames are most widely used. However, it is necessary to take into consideration the fact that the rigidity of assembled frames is somewhat less than of a cast solid one.

Besides the requirements stated above, the constructor should provide enough clearance between the workpiece and the frame sides when he constructs the frame. The clearance helps to carry out free workpiece installation and removal. In order to provide convenient removal of cutting chips and withdrawal of cooling liquid, one should avoid cavities and nooks in the frame construction, and also one should provide special openings.

5.2 Ways of installing the frames of retaining devices on the machine

The devices are installed on the machine matching site with the help of the basing surfaces of the frame. Shape, size and critical dimensional features of all machines are standardized, and the information on them is given in the catalogues, reference books and machine certificate.

The device frames on the lathe machines are often joined directly with the work spindle through the auxiliary element – the back plate. In practice, the following ways of installation are used: in the centers, in the spindle cone hole and on the spindle, and also in the back plate.

By installing in the centers, the device frame is installed in the form of a mandrel is centered on the cones with its base centering holes; the cones are installed in the machine spindle and tailstock ram. The mandrel is rotated by the warpage device that is connected to a spindle. In this case, the installation is highly accurate. This method gives the opportunity to use the same device on any lathe machine.

When the devices are installed on the back plates, the latter have mounting surfaces made in the shape of the spindle matching seat on the left side, and the centering collar on the right side. The device frame has the centering groove that equals to collar flange diameter. It is recommended that the groove diameter is made with the seating fit ***H7*** or

H6. The device frame is joined with the back plate with the screws.

On milling, boring, drilling, multicenter machines, the device frame is installed with its basing surfaces on the table with T-shaped slots.

Let us consider the device frame installation on the milling machines. The machine table is the matching seat for the device installation. The device frame has basing surfaces on its bottom; they contact with the table plane. In small devices, the matching seat is a solid plane. Large devices have a shallow cavity or hollow in their middle part. This way, the device frame middle part doesn’t touch the tale plane, and the frame itself is installed stable enough. For fixing the device, the frame base has ears, in which the fixation bolts are inserted. The bolt heads are held in the T-shaped slots on the table. The number of bolts, and, consequently, of ears, is chosen depending on the cutting forces applied. In most cases, two ears are enough.

The device often needs to be installed in a certain position on the machine table relatively to the direction of line table feed. In this case, the device is directed with the help of prism bushing keys, the direction of which directly coincides with the direction of line table feed. Standard prismatic bushing keys (ГОСТ 14737-69) are most widely used (Fig. 5.2).

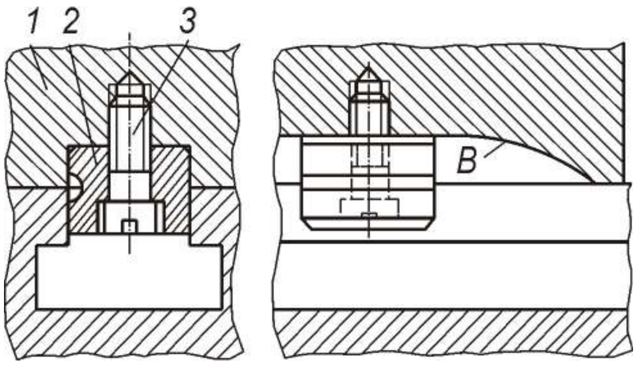


Figure 5.2 – The way of fixing the bushing keys in the device

The width of the bushing key is its main dimension; it should be equal to the width of the T-shaped slots and it should be manufactured with the accuracy of the ***h8*** workmanship.

Two bushing keys are installed on each device. The bushing key 2 is installed on the frame 1 on the bottom of the device in a specially provided slot ***B*** and fixed with the screw 3 (see Fig. 5.2).

Because of the wear and following repairs, the width of the slots on the machine tables often exceeds the tolerance limits, which leads to increasing the clearance between the device bushing keys and the table slot. In these cases in order to prevent the possible rotation of the device on the table during its installation it is pressed with the bushing keys to one side of the table slot, thus reducing the basing error.

5.3 Devices for drilling machines

The devices for drilling machines that serve for basing and fixing the treated workpieces and that are equipped with directional elements – aligning bushings – are called ***jigs.*** The aligning bushings determine the position of the cutting tool (drill, core drill, reamer bit, etc.) relatively to the device installation surfaces by machining the holes in the workpiece.

The following types of jigs that differ with design peculiarities are most widespread: template, roof jigs, jigs with folding clamp bar, tinted rotary jigs.

Template jigs are used for machining one or several holes with parallel axes in large workpieces. They have simple design: they consist of a jig plate with aligning bushings, location elements and clamping devices. The jig is installed (laid on) the workpiece and fixed on it.

Cylindrical and rhombic fingers that are situated on the jig plate are used as the jig installation elements that determine the position of the machined holes relatively to the workpiece basing surfaces. The jig is fixed on the workpiece with an L-shaped screw clamp. Fast-change aligning bushings are installed into stationary bushings and fixed by turning. Usually, large and medium jig plates have selections in the form of holes, windows, cavities for reducing the construction mass.

Roof jig, unlike template jig, has frame elements for installing it on the machine table. Besides, the frame has location elements for the treated workpiece. The jig plate (roof) in this case is made removable or folding, it has aligning bushings installed in them. The jig plate has accurate position relatively to the location elements. The design of the jig with the folding jig plate is shown in the Fig. 5.3.

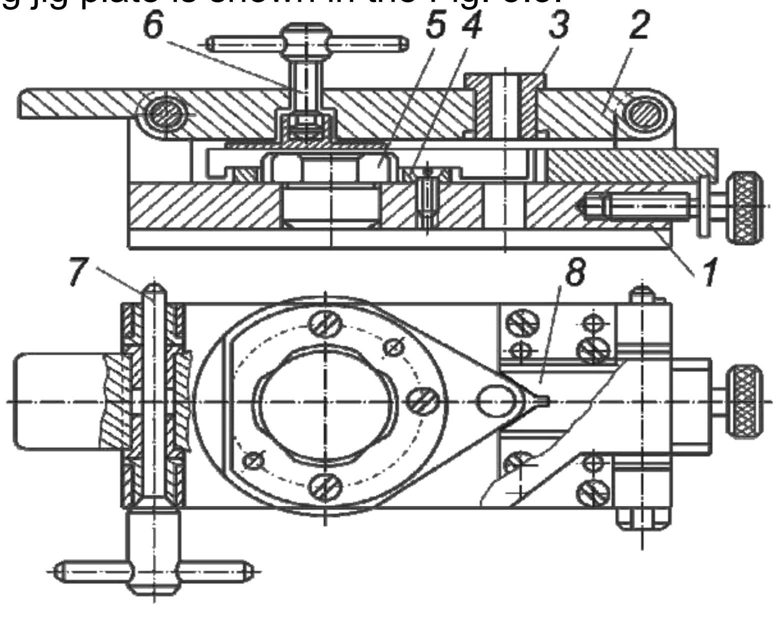


Figure 5.3 – The jig with a folding plate

Frame 1 is pivotally connected with the jig plate 2, in which the aligning bushing 3 is pressed. The jig plate is tilted before the installation. The workpiece is installed on the finger 5 with the abut on the ring bearing plane 4. The workpiece is fixed in the angular position with the prism 8. After the workpiece installation, the folding plate is put down and joined with the frame with the fixing finger 7. The workpiece is fixed with the clamp 6.

Jig with folding clamp bar has open or closed frame. Its peculiarity is that aligning bushings are placed directly in the frame sides. This allows increasing the accuracy of treating the holes, as the absence of the jig plate leads to reducing the number of individual errors. The jig with the closed frame is used when there is the possibility to install and remove the workpiece conveniently.

Fig. 5.4 shows one of the variations of the jig with folding clamp bar and open frame for drilling two holes in the roof flange.

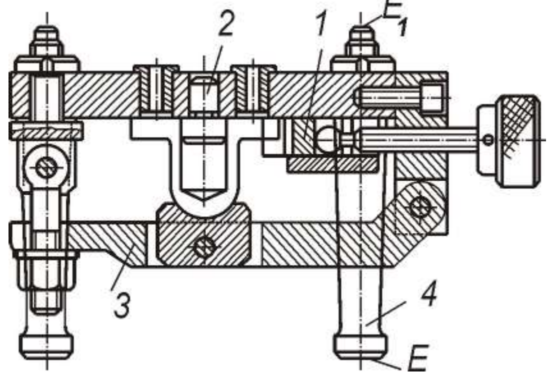


Figure 5.4 – Jig with folding clamp bar

By installing the workpiece, the jig stands on the bearing edges $\boldsymbol{E_1}$ of the bases 4. The arm clamp bar 3 is thrown back. The workpiece is installed on the finger 2 and fixed in the angular position with the prism 1. The clamp arm fixes the workpiece. After this, the jig is turned over and installed in the working mode with the edges ***E*** of the bases 4 on the machine table.

Canting jigs are used for machining the holes in small workpieces (bushings, rollers, flanges, rings, etc.), the axes of which are situated radially or on the edge planes of the workpiece. The number of jig frames' bearing (basing) surfaces for installing it on the machine table is the same as the number of positions in space that the workpiece takes during the operation. The jig should be turned (canted) from one bearing surface to another during the operation. The bearing surfaces are made in the shape of planes or legs.

Rotatory jigs are used for machining the holes round the circle of the workpiece end surface or radially in one section. Unlike canting jigs, they include the dividing device that allows turning and installing the workpiece into the next position relatively to the aligning bushing on the frame.

Rotatory jigs may have vertical, horizontal and inclined axis of rotation. The rotation axis chosen depends on the position of the treated holes in the workpiece.

5.4 Peculiarities of the devices for the numerically controlled machines

Efficient usage of highly productive numerically controlled machines greatly depends on the level of correspondence of the devices used. That is why there are a number of specific requirements for the devices that are caused by certain peculiarities of the numerically controlled machines, inobservance of which considerably reduces their working efficiency [11-13].

The devices must have *particular accuracy*. The errors of basing and fixation that occur by the workpiece installation into the device should be reduced to minimum. In order for the machine to use full capacity during rough treatment, the devices must have *particular accuracy*. At the same time, the device construction should provide high accuracy on finishing operations.

The relative shift of the workpiece and the tool on the numerically controlled machine is carried out in the system of preset coordinates. Therefore, the workpieces should have *full basing* in the devices. The workpiece bases should have the strictly defined position relatively to the machine coordinates origin (zero point).

In order to provide automatic orientation of the bearings relatively to the coordinates' origin, the device should have accurate and full basing on the machine and it should strictly define its position relatively to the zero point of the machine. Numerically controlled machines may treat up to four-five surfaces from one workpiece installation. For this, the devices should *provide the approach of the tool* to all treated surfaces.

In order to reduce idle time of the numerically controlled machines that is spent on changing the workpieces, the time of the workpiece fixation and release should be reduced, as it is dominating. The possibility of treating as many sides of the workpieces as possible in one installation on a numerically controlled machine significantly increases the machining cycle of the workpiece on one machine, which conditions changing the workpiece outside the machine working area or outside the machine while treating another workpiece. Therefore, the devices should provide the possibility of changing the workpieces during the machine operation.

On numerically controlled machines, readjustment is made only by changing the input medium. The most preparation and finishing-up time goes for changing or readjusting the equipment – the devices and tooling. That is why in order to reduce idle time, the machines should have a possibility of quick readjustment or changing. The numerically controlled machines effectively use the system of readjustable devices that provides machining of wide range of workpieces due to rearrangement, changing or regulating the installation and clamping elements.

6 DESIGN TECHNIQUE OF MACHINE RETAINING DEVICES

6.1 Initial data for design

The practice shows that about ***60...65%*** of the general number of machine retaining devices used for machining the workpieces are designed and produced by the manufacturers themselves, and only ***35...40%*** are universal and modular accessories. Out of the whole number of the devices, ***30...35%*** are specialized readjustable devices, and ***65...70%*** are special undismountable devices.

The job of a constructor is closely connected to the one of a technologist. While developing the technological process of manufacturing the detail, the technologist finalizes operation sheets and tool layouts, in which he indicates the installation scheme of the treated workpiece, i.e. its basing and fixing, the sequence of machining the surfaces (operating steps), accuracy of the performed geometrical parameters, name and type of the device, machine used, weight and material of the workpiece, and cutting mode. All these data allow determining the structural scheme of the intended device. Basing upon the operation sheets, the technologist makes up a task on designing the device.

The device constructor turns the technologist's idea into a real construction. Here, the constructor, saving the structural scheme proposed by the technologist, develops and analyzes different variants of the device design and chooses the most optimal one, which corresponds to all the requirements of carrying out the operation. This variant is agreed with the client, and after this the design drawings of the construction and the details are formalized.

The constructor should have the following basic data in order to design the device:

- design drawings of the detail and of the primary workpiece;
- operation sheet with the draft of the workpiece treated in the given operation with its basing and fixation schemes;
- operation sheets of the upstream operations, according to which the basing surfaces used for fixing the workpiece in the given operation were machined;

- annual amount of the details manufactured;
- ratings of the machine, for which the device is designed.

By designing a specialized readjustable device, it is necessary to have basic data for all identities of the workpieces that will be machined in the designed device.

Besides these data, the constructor should as well have additional materials: the books of standard designs of multipurpose, specialized and special devices, standardized preformed materials, power drives, mechanisms and devices' elements; information on the shape and size of the matching sites of the machines, on which the devices are installed and fixed; information on the construction materials used for designing the device; and also technologic guidance materials and reference books that are necessary for making technical and economic assessment on justification of the device designed.

The design of machine retaining device is carried out in the following order:

- basic data is studied and variants of the device construction schemes are developed;
- technical and economic assessment on justification of the optimal variant of the device;
- design of the optimal variant of the device is developed.

Analysis of the design drawings allows getting the full idea of the shape, size, technical requirements and other peculiarities of the detail and the workpiece.

Considering the operation sheet for the given operation is of high importance, as the constructor uses it for determining the installation scheme, accuracy requirements and other machining requirements, consequence of operating steps, workpiece material, cutting mode, etc.

In addition to this, the constructor needs to know the shape, size, accuracy, rigidity and position of the basing surfaces and the places of the workpiece fixation in the given operation. All these qualitative characteristics have a significant impact upon choosing the right installation and clamping elements, and of the general design of the workpiece.

For example, the installation error is directly connected to the accuracy of the basing surfaces; short basing surfaces require special design solutions to provide correct and reliable installation of the workpiece. When there is low rigidity or small area of the surfaces for the workpiece fixation, the constructor has to calculate the surface deformation under the impact of clamping forces and also the reliability of fixation. If the received results do not comply with the working conditions, the workpiece requires additional devices for fixation.

Detailed data on basing surfaces and fixation places may be received from operation sheets of upstream operations, according to which these surfaces were treated. If the device is for the first machining operation, basing and clamping surfaces of the basic workpiece should be thoroughly examined.

Manufacturing rate of the details and labor input of the operation allows the designer to determine the efficiency of the process and outline the level of mechanization and automation of the device designed.

When considering machine data, it is necessary to pay attention to the shape and size of matching sites, on which the workpiece is installed and fixed (shape and size of turning machine spindle ends, grooves on the tables of milling machines, etc.).

Along with considering the basic data, it is necessary to get acquainted with typical designs and standardized preformed materials of the devices.

On the basis of considering the basic data and typical designs, the constructor develops the variants of the device designs, and on the basis of that chooses the most optimal one. Engineering design includes analyzing the accuracy of the geometrical parameters performed and reliability of their fixation in the devices. Value engineering is connected with estimating the appropriateness of using the device and determining its efficiency.

The analysis begins with determining the device's accuracy. If the device doesn't meet machining accuracy requirements, this variant isn't suitable for production.

Accuracy analysis of the device is carried out according to the methodology given in Subsection 1.2.

Determining the installation error of the workpiece is of high importance for the designer. The error $\boldsymbol{\omega}_y$ mainly depends upon the choice and accuracy of the workpiece installation bases, design of the installation elements, accuracy and wear of installation elements and other elements of the device that may impact the installation error.

The basing error is determined by means of calculation. Typical basing schemes and accuracy calculation are considered in Section 2.

One should bear in mind that usually several surfaces of the workpiece are machined during one operation; therefore, several geometrical parameters are set. That is why the workpiece installation error should be determined for every parameter of the workpiece treated.

Sometimes by extended calculations of installation accuracy, the installation error in multipurpose devices (chucks, mandrels, vise units) may be determined by the statistic data given in the reference book [12].

The next step is calculation of the workpiece fixation reliability.

After determining the required workpiece fixation force, the designer finally chooses the design of the clamping device and the gear drive.

Design formulas, schemes of clamps and gear drives are given in Section 3.

6.2 Development and design of the general look of device construction

Machine retaining devices are designed in a certain sequence. At first, usually the machined workpiece is outlined in a projective bound with thin lines. The projections are placed in such distance from one another, so that there is enough space to place there the corresponding elements of the device.

Then, installation and clamping elements on these projections are drawn, and if the device has directional or separatory elements, they are also marked on the drawing. After that, the device frame is designed. When making the frame, one should tend to a more simple design, which will allow manufacturing it from standard workpieces. Finally, additional details and other missing parts are drawn.

General look of the device is represented in the operating position, The drawing includes all the necessary projections, sections and sectional arrangements that give full representation of the design of all device elements and their interconnection (Fig. 6.1).

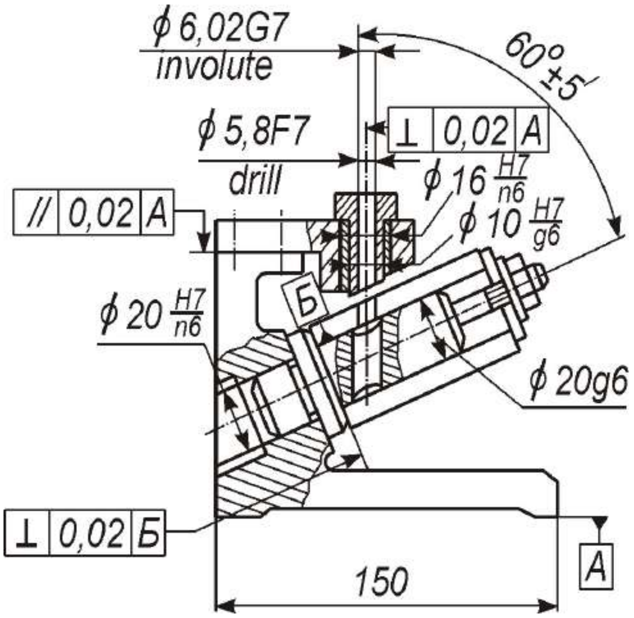


Figure 6.1 – Sample design of the general look of a special machine retaining device

When designing a special machine retaining device, the constructor tends to use as many standardized and normalized details and joints as possible. This allows to reduce the design labor intensiveness by about ***25%*** and reduce the device manufacturing cost by ***20...30%***. The size and shape of the device original details are determined on the basis of the strength calculations or they are chosen for the reasons of design.

Mechanical properties of the elements' materials should provide strength and rigidity of the device construction. A number of elements (directional, installation, separatory and self-aligning) have wearability as main criteria by choosing the material, as their wear directly influences the accuracy of the parameters of the machined workpieces.

General look of the workpiece is drawn, as a rule, at scales of 1:1. It includes overall, coordinating and coupling dimensions, dimensions of directional elements, and also the dimensions of the surfaces that connect the device with the machine. Besides that, certain technical requirements are set to determine the accuracy of assembling the device and its mounting on the machine, operating conditions, terms of control of the device accuracy parameters.

6.3 Machine design of retaining devices

Automated design of the device is the process of algorithmic synthesis of constructional elements. Here, under ***construction element*** one means a part of the construction that would be rational to divide into smaller parts while designing. The following may be called constructional elements: assembling unit, detail, part of a detail (surface, group of surfaces). The device construction is viewed as a variety of spatially organized and metrically determined constructional elements, with each of them having certain geometrical, physical, technological, functional, and other properties.

Creation of the device automated design system is inseparably connected with normalization, standardization and unification, as the design of the devices of standard elements and setting operations using typical schemes may be done with computer by relatively low costs.

6.3.1 Algorithmic design of devices' elements

The process of the device automated design may be divided into a number of sequentially performed stages. Here, at each stage, the projection of one of the elements' functional groups that make up the device is provided.

Classification of the elements of the device construction by functional features plays rather important part in algorithmic design. Differentiation of the elements by their functional features quickens the search of the needed element because of narrowing the area of such search. In accordance with the functional classification of constructional elements, the general structure of the whole process by stages is developed: design a functional class of a construction element corresponds to a stage of automated design.

According to functional features, constructional elements of the devices are divided into the following classes: installation, clamping, directional elements for cutting instruments, separatory elements.

When designing constructional elements, there are elements of the first, second, third order, etc. Constructional elements that are connected directly with the main coordinate system of the designed device are called constructional elements of the first order. They include all functional elements of the device: installation, clamping, directional elements, etc.

If constructional elements go into the device construction and are connected to it by means of the elements of the first order, the part of which they are, they are called constructional elements of the second order. They include details of the joints, if the element of the first order is a joint. If constructional elements of the second order include, in their turn, constructional elements, the latter are called constructional elements of the third order.

During algorithmic synthesis, the construction of the machine retaining device undergoes some changes, turning from one condition to another. Boundary state of the construction is a state, after which the synthesis of constructional elements of one class is completed, and there begins the synthesis of the elements of the next class or the machine end stop occurs (Fig. 6.2).

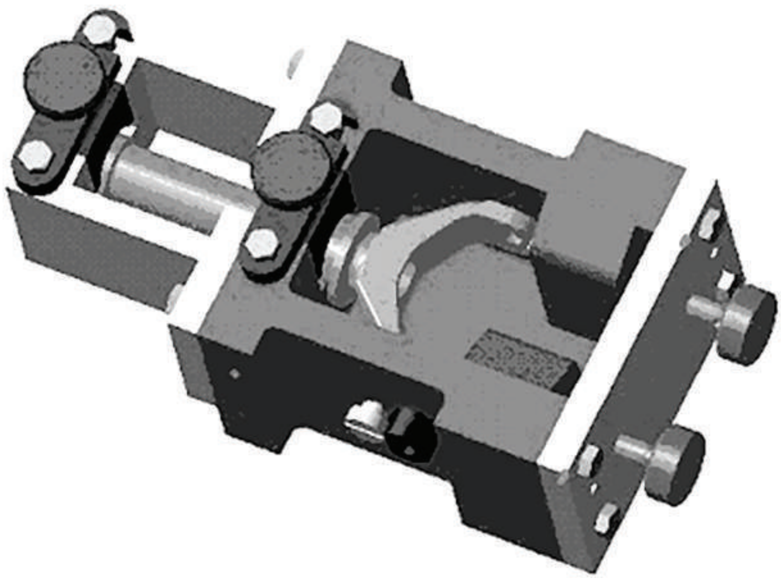


Figure 6.2 – Computer model of rigid-body jig

The process, during which the construction changes within its two sequential conditions, is called ***design phase***. Most phases are two-stage: during the first stage, the principal construction scheme is chosen, and during the second one the design is carried out.

Initial data for algorithmic design of the device *installation elements* is the information about the machined workpiece, and in the first turn, the information about installation and treated surfaces, about the accuracy of their mutual placement.

The scheme of the workpiece installation into the device is largely predetermined by the number, shape and mutual placement of installation surfaces of the workpiece machined, i.e. the accepted basing scheme. In general case, for full and definite orientation of the workpiece in space (i.e. for removing all six degrees of freedom from it), two or three installation surfaces are needed in each basing scheme.

Developing the construction algorithms for *clamping devices* is one of the most responsible stages of automating the processes of the equipment design.

After the data on the positions of the clamping elements in space is received, the force calculation of the “workpiece – device” system is made and the clamping force required for each element is determined.

The next stage of designing the fixation scheme is checking the possibility of installing the clamping elements by estimate calculations, taking into consideration the webbing, lugs, and cavities in this place. When there is an intersection, the adjustment of the clamping element size or shape position is foreseen.

After determining the final position of the clamps and calculation of the necessary clamping force, the dimension types of the elements that form the fixation scheme, are finally adjusted.

The design of *directional elements* begins from choosing the type of aligning bushings (fixed-type, changeable, fast-change, special). The conditions of their usage are main criteria of the choice.

Orientation of changeable and fast-change bushings is chosen in such a way that their fixation joint is situated on the side of the jig plate fixation.

On the stage of the device *embodiment*, the following matters are solved: determining the number of plates in one device, their orientation in space, determining the overall dimensions and shape of each plate separately. Determining the positions of the holes for aligning bushings, as well as designing the device elements installed on this plate, take important place in the device embodiment.

The shape of the jig plate may be adjusted in the case where it is impossible to place separate functional elements of the device without intersections. The embodiment of the plate is finished with designing the various auxiliary elements, such as handles, buttons, bosses, etc.

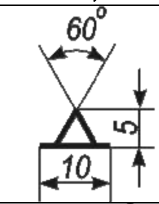
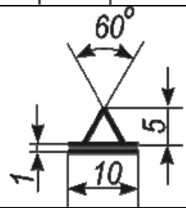
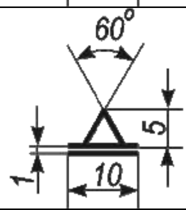
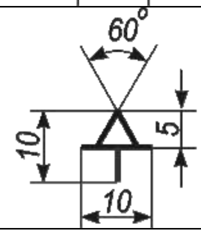
Frame is the main part of the device; it adjoins into one operable mechanism all its functional elements: installation, clamping, directional, etc. That is why the design of the device frame is mainly determined by the nomenclature and mutual placement of the elements fixed on it, and also by the size and shape of the treated workpiece. The frame should have basing surfaces for its connecting with the machine.

APPENDIX

(reference)

The following appendix includes graphical symbols of the bearings, clamps and installation devices used in technical documentation. To denote bearings, clamps and installation devices, one should use thin solid line according to the ГОСТ 2.303-68. Notation conventions of the bearings are given in Table A.1.

Table A.1 – Notation conventions of the bearings

Identity of the bearing	Notation of the bearing on the views		
	Front, back	Top	Bottom
Immovable			
Movable			
Floating			
Regulated			

Notation conventions of the clamps are given in Table A.2.

Notation of the double clamp on the front or back view, when the points of force application coincide, may be drawn as the notation of a single clamp on similar views. For double clamps, the designer sets the arm length ***L*** depending from the distance between the points of force application.

Notation conventions of the installation devices are given in Table A.3.

Notifications of the bearings and installation elements, except for the centers, are allowed to be marked on the extension lines of the corresponding surfaces.

Table A.2 – Notation conventions of the clamps

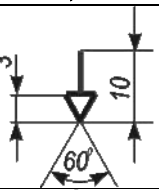
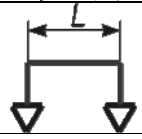
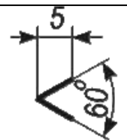
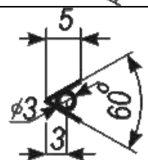
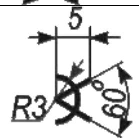
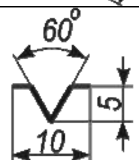
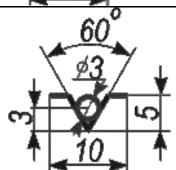
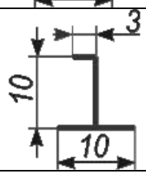
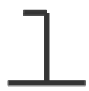
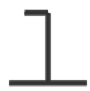
Identity of the clamp	Notation of the clamps on the views		
	Front, back	Top	Bottom
Single			
Double			

Table A.3 – Notation conventions of the installation devices

Identity of the installation devices	Notation of the installation devices on the views		
	Front, back, top, bottom	Left	Right
Immovable center		Without notation	Without notation
Rotating center		The same	The same
Floating center		»	»
Cylindrical mandrel			
Ball mandrel (roller)			
Carrier plate			

For marking the shape of the working surface bearings, clamps and installation elements on all views, the notifications should be used according to Fig. A.1.

Installation and clamping devices should be marked as the combination of notifications of installation devices and clamping devices.

Notifications of the working surface shapes are marked to the left of the notification of the bearing, clamp or installation device.

Notification of the working surface relief is marked on the notification of the corresponding bearing, clamp or installation device.

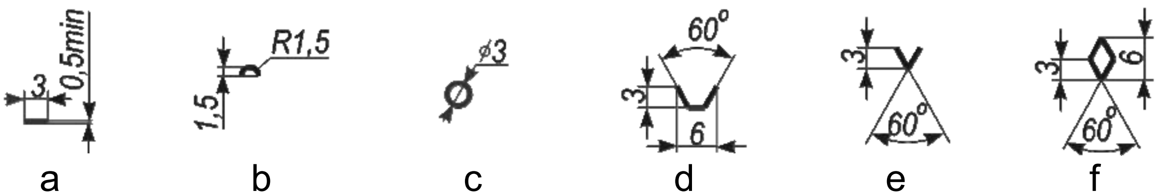


Figure A.1 – Notification of the working surface shape:
a – flat; b – spherical; c – cylindrical (ball); d – prismatic; e – conical;
f – rhombic

For marking the clamping devices’ identities, one should accept the following notifications on all views: pneumatic – ***P***; hydraulic – ***H***; electric – ***E***; magnetic – ***M***; electromagnetic – ***EM***; others – without notification.

Notifications of the clamping devices’ identities are marked to the left from the notifications of clamps.

The number of force application points to the item, when it is necessary, should be marked to the right from the notifications of clamp.

On the schemes that have several projections, it is allowed not to mark the notifications of the bearings, clamps and installation elements on separate projections relatively to the item if their position is definitely determined on one projection.

On the schemes, several notifications of similar bearings are allowed to substitute with one, indicating their number, to the right.

The examples of marking the bearings, clamps and installation devices on the schemes are given in Fig. A.2.

According to the ГОСТ 3.1109-82, the ***tool setting block*** is a part of the technological operation that is performed by constant fixation of the workpiece. The examples of the tool setting blocks’ schemes are shown in Fig. A.3.

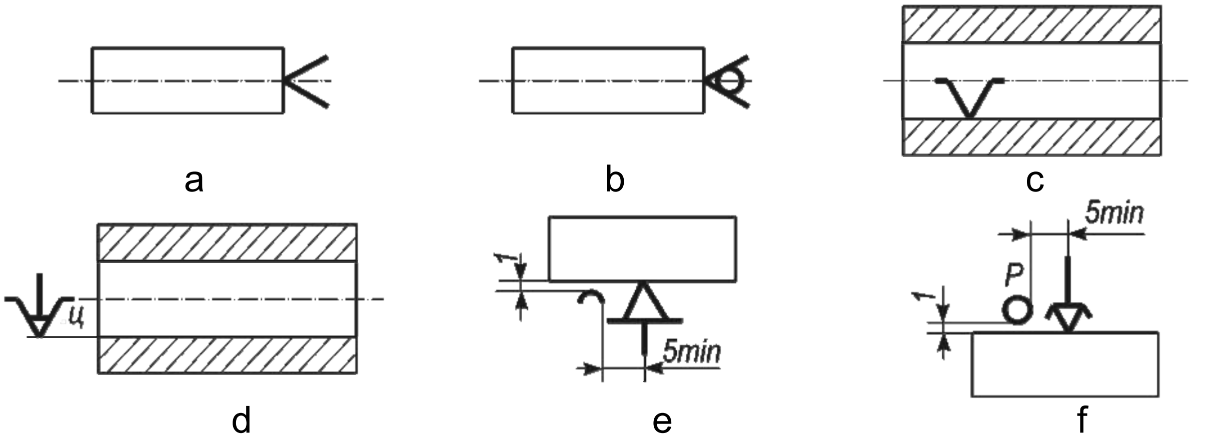


Figure A.2 – Examples of marking the notations of the bearings, clamps and installation devices: a – the center is immovable; b – rotating center; c – cylindrical mandrel; d – collet mandrel; e – adjustable bearing with spherical domed working surface; f – pneumatic clamp with cylindrical corrugated wording surface

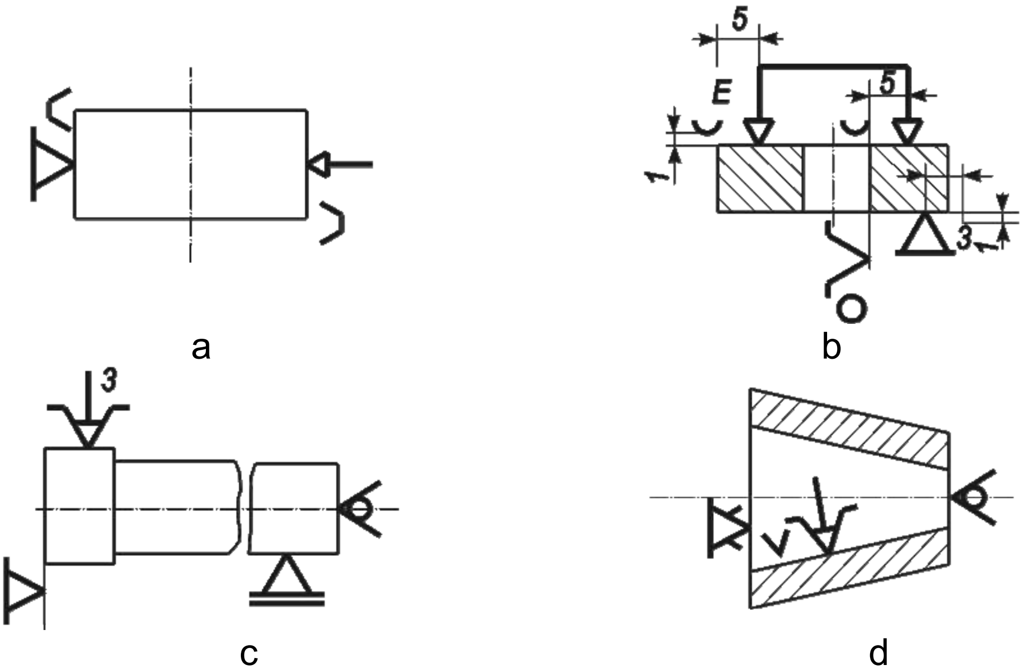


Figure A.3 – Examples of the workpiece tool setting blocks: a – on the V-block vise; b – on the jig with centering on a cylindrical finger, with basing on the three bearings; c – on the three-jaw chuck with mechanical clamp, with its rest at the end, with movable rotating center and with fixation in the movable backrest; d – on the angle drift with its rest at the end on the corrugated surface and with tightening rotating center

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