Tomsk Polytechnic University

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TECHNOLOGY of MECHANICAL ENGINEERING

Part 2 (parts b)

Textbook

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This textbook is devoted to technological opportunities of machine tools and designing of technological processes

The textbook is prepared at the Department of Mechanical Engineering of Tomsk Polytechnic University. It is recommended for foreign students following the Bachelor Degree Program in Mechanical Engineering at Tomsk Polytechnic University.

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PREFACE

The discipline "Technology of Mechanical Engineering" is a finishing rate in preparation of the experts under the program "Mechanical Engineering". For its study the knowledge of disciplines "Processing of materials", "Resistance of materials" is required.

The discipline "Technology of mechanical engineering" is studied on the senior rate for the bachelor level in 7 and 8 semesters and is divided into two parts. The part "Fixing of accuracy in mechanical engineering and bases of the theory of cutting tools" are studied in the seventh semester (3 credit.) The part second "Technological opportunities of machine tools and designing of technological processes" is studied in the eighth semester (3 credit.) At the end of each semester the examination in the appropriate parts is stipulated.

This textbook provides the most comprehensive introduction to technology of mechanical engineering. Measurements throughout the textbook are given according to the SI Metric system of measurement. The content is generously illustrated, and the language used is simple and direct.

This text book is written on the basis of the book of Victor E. Repp and Willard J. McCarthy “Machine Tool Technology”. The author of this textbook expresses gratitude to the authors of the book for the given opportunity to use its material.

Suggestions on improvements of future editions of the textbook are welcome.

Welcome to the textbook.

Chapter 23. Nontraditional Machining Processes

Electrical discharge machining (EDM) removes metal by controlled electrical arcing (sparking) between the tool and workpiece. Each of thousands of tiny arcs vaporizes a tiny amount of the work-piece, leaving a miniature crater in the metal's surface. A dielectric (insulating) fluid confines the arcing to the immediate vicinity of the tool. The most commonly used dielectric fluids are low-viscosity petroleum oils, kerosene, deionized water, silicone oils, and ethylene glycol/water solutions. The arcing shapes the workpiece to a mirror image of the shape of the tool. Figure 23-1 shows the basic parts of an EDM system. EDM electrodes must be good electrical conductors. Commonly used materials include high-purity graphite, brass, copper-graphite, copper-tungsten, and zinc alloys.

The EDM process is valued for its ability to machine complex shapes in metals of any hardness. It is used widely in making injection and compression molds for rubber and plastic molding, molds for die-casting metals, and dies for forging and metal stamping. EDM can also be used to remove broken taps and studs and to drill holes as small as 0.05 mm. Because no tool pressures are involved, the process is ideal for machining delicate workpieces such as honeycomb structures.

EDM has two main disadvantages: (1) only materials that conduct electricity can be machined, and (2) machined surfaces are left with a thin (usually less than 0.025 mm), hard layer of metal. This makes it difficult to file and polish EDM-machined die cavities. However, it has been found that **electropolishing** (a form of electrochemical machining) can efficiently remove this hard layer.

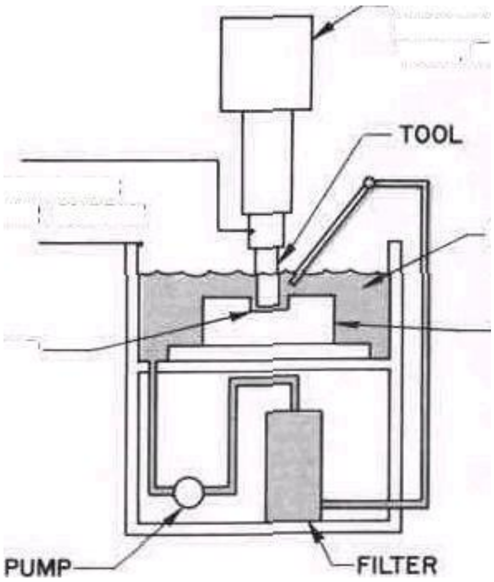


Fig. 23-1. The basic parts of an EDM system.

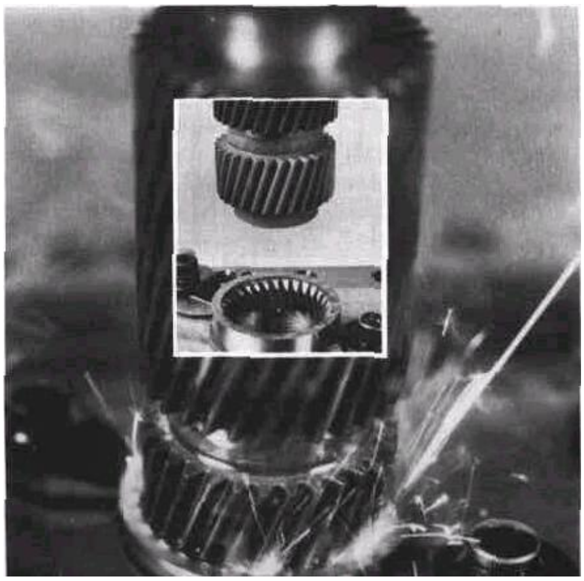


Fig. 23-2. Helical gears and other helical parts can be cut on EDM machines equipped for tool rotation.

There are two types of EDM machines: those that use solid electrodes and those that use a traveling-wire electrode.

Solid-electrode machines vary in size from small bench-top models to machines capable of handling huge workpieces. Basic machines of this type work by advancing a nonrotating tool directly into a workpiece. More versatile machines revolve the tool as it advances. This feature permits helical cutting operations such as tapping holes and cutting internal helical gears, Fig. 23-2. The advanced machines may also have worktables equipped with power feeds to permit sawing and slotting operations.

EDM machines with automatic tool changers and computer numerical control (CNC) are also available. CNC can provide numerous benefits, including:

1. Automatic tool centering over the workpiece.
2. Precise workpiece movements for accurate hole patterns.
3. Programmed orbiting of the electrode (movement of the electrode in a tight circular path without rotating the electrode), which aids flushing of cutting debris, prolongs tool life, and improves the accuracy of the machined part.
4. Programmable tool withdrawal to promote flushing.
5. Automatic tool changing.

Traveling-wire electrode machines are also made in several sizes. The tool or electrode for this type of EDM machine is a round wire. As a part is machined, unused wire electrode is fed continuously from a supply reel through the workpiece to a take-up reel. Used wire is discarded.

Traveling-wire machines have revolutionized the making of blanking dies for sheet metal stamping. With a round wire electrode, cutting is possible in any direction, and any shape can be cut. Die blocks may be hardened before being cut with a traveling-wire machine and the shapes can be cut exactly to size. Both punch and die can be made from the same block, the clearance being determined by the diameter of the wire used for cutting.

Production versions of traveling-wire EDM machines are also available. One such machine has five wire feeds, each with its own power supply. All of the wire feeds are under the control of one numerical control unit. With this machine, it is possible to stack and machine seven parts at each work station rather than machining only one part per station. This boosts production from five to 35 parts for each machining cycle.

In EDM, the metal removal rate is directly related to amperage setting and arcing frequency. When clean oil with a dielectric strength of 200 volts per 0.02 mm is used with the voltage set at 200, arcing will begin when the tool is 0.02 mm from the workpiece. If the voltage is reduced to 100, the gap must be reduced to 0.01 mm. However, when cutting begins, metal particles become suspended in the gap, forming a conductive path which effectively increases the overcut.

At a constant frequency, low amperage setting produce slow rates of metal removal and good finishes, while high amperage setting produce higher rates of metal removal and poorer finishes. At a constant amperage, low arcing frequencies produce rougher finishes than high arcing frequencies. The best surface finishes are therefore obtained when the controls are set for the highest arc frequency and the lowest amperage. Finishes as fine as 0.25 micrometers are possible with EDM.

Cutting rates vary widely when a given metal is cut with different electrode materials and when a given electrode material is used to cut different metals. Graphite electrode cutting rates exceed other electrode cutting rates from 2:1 to as much as 20:1. The average cutting rate for graphite electrodes cutting steel is generally less than 0.32 cubic centimeters per ampere per hour, making **EDM a very slow process**. For this reason, conventional machining methods are used for the bulk of metal removal in order to minimize EDM machining time.

Safety

In EDM, cutting occurs by electrical arcing in what is essentially an open circuit, and electrical potential can reach 400 volts. Therefore, **under no circumstances should the operator touch the tool, toolholder, or workpiece while the machine is in operation.** When cutting has been completed and the machine has been turned off, the voltmeter should read **zero** before the operator handles the tool, toolholder, or workpiece.

While dielectric oils have low flammability, the gases produced in the breakdown of the oil by the electric arc contain a high percentage of acetylene, which is very flammable. **Since the acetylene can be ignited by the arcing between the tool and workpiece, cutting should never be started until the tool and workpiece have been flooded with at least 25 mm of oil.** While industrial experience has shown that the fire hazard is very slight, it is strongly recommended that a class B and C fire extinguisher be placed near the machine.

Electrochemical machining (ECM) is based on the same principles as electroplating. However, instead of depositing metal on the workpiece, ECM reverses the process so that metal is **deplated** or removed from the workpiece.

In ECM, the tool is the cathode and the workpiece is the anode. A gap of 0.0254 mm to 0.76 mm is maintained between the tool and workpiece. This provides space for the flow of the electrolyte and keeps the electrical circuit from shorting out. A low-voltage, high-amperage direct current passes from the workpiece to the tool through the electrolyte. This current dissolves metal particles from the workpiece into the electrolyte by electrochemical reaction. The electrolyte is pumped through the gap between the tool and workpiece at pressures from 1 379 to 2 068 kPa (200 to 300 psi). The dissolved metal particles are swept away and filtered out. They are thus prevented from being deposited on the tool.

The accuracy of the ECM process and the life of ECM tools are very good for these reasons: (1) the tool never touches the workpiece, (2) the tool receives no build-up of metal from the workpiece, and (3) the tool has almost no wear from the flow of the electrolyte.

ECM electrodes (tools) are most commonly made of copper and copper alloys, type-316 stainless steel, and titanium. Copper and brass are preferred except for thin tools requiring greater stiffness. Tools must be made undersize to adjust for overcut, which varies depending on the electrolyte flow and the required accuracy.

The electrolytes most commonly used are water solutions of sodium chloride, sodium chlorate, potassium chloride, sodium nitrate, and sodium hydroxide. Electrolytes must be continuously filtered to remove dissolved metal. Close control of electrolyte temperature is also required, since changes in temperature greatly affect the electrical conductivity, machining rate, and accuracy.

The ECM process can be used to machine any metal that conducts electricity, regardless of hardness. The absence of tool pressures on the workpiece makes the process ideal for machining thin metals and fragile workpieces.

Comparatively low metal-removal rates prevent ECM from competing with conventional machining methods when metals with good machinability are involved. ECM cutting rates range from 0.65 cubic centimeters to 1.74 cubic centimeters per minute per 1000 amperes, depending on the kind of metal being cut.

ECM excels in machining difficult-to-machine metals, especially when holes or cavities of complex shape must be made. No burrs are made by ECM. Surface finishes are bright and smooth, ordinarily Ra is equal to 0.1- 0.75μm, and usually do not need polishing.

Electrochemical deburring (**ECD**) is an adaptation of ECM. The tooling used in this process is designed for removal of burrs and sharp edges from parts machined by conventional methods.

Safety

Sodium nitrate and sodium chlorate compounds are powerful oxidizers, which accelerate combustion. They must never be exposed to combustible materials. These compounds are also dangerous to body tissue, thus requiring protection against inhalation of dusts, mists, and vapors. Protective clothing and face shields or masks are also required for handling acids and certain other chemicals used in ECM. Further, explosive hydrogen gas, released by the electrochemical reaction, must be vented from the top of the work enclosure to prevent explosion.

Electrochemical grinding (**ECG**) applies the principles of ECM to the conventional grinding process. ECG grinding wheels are composed of conventional abrasives but must be made with an electrically conductive bond. ECG removes metal as much as 80% faster than conventional grinding without an appreciable loss in accuracy or surface finish. Grinding operations can often be completed in one pass of the grinding wheel. Only about 10% of conventional grinding wheel pressure is necessary. Since 90% of the metal is removed by electrochemical reaction (deplating), wheel dressing and wheel wear are sharply reduced.

The ECG process is preferred for grinding carbide tools because cutting edges can be ground with a single pass. With conventional grinding, several passes are normally necessary because heat build-up limits material removal to 0.02 mm per pass. Additional ECG benefits include smooth, burr-free cutting edges and wheel wear reduced to 15% of that for conventional grinding. ECG is also used to a limited extent for surface grinding and cylindrical grinding.

Chemical machining (CHM) is a process of shaping metal by using strong acid or alkaline solutions to dissolve away unwanted metal. There are two types of chemical machining: **chemical blanking** and **chemical milling.** Chemical blanking is used for cutting out parts from thin sheet metals. Chemical milling is used for selective or overall removal of metal from thick metal parts.

Parts to be made by chemical blanking are first accurately drawn up to 20 times their actual size, depending on the accuracy required. The enlarged drawing is then photographed and reduced to produce a negative exactly to required size. A multiple negative having many images of the part may then be made. An acid-resistant coating is applied to the metal to be cut. Then the negative is used to make a contact printing directly on the metal surface. An etching solution is used to dissolve the light-exposed portions of the metal, leaving the workpiece(s) blanked accurately to size and shape. Parts made by chemical blanking are usually etched from both sides simultaneously to speed processing.

Chemical milling is most widely used in the aircraft and aerospace industies. This process makes possible the efficient removal of unwanted weight from large, complex airframe parts without sacrificing strength.

In **ultrasonic machining (USM)**, also called **impact grinding,** fine abrasive particles suspended in a fluid (usually water) are pumped into a gap between the workpiece and the tool. The tool is made to vibrate a few hundredths of a millimeter at ultrasonic frequencies ranging from 19,000 Hz to 25,000 Hz. The rapid pumping action of the tool hurls the abrasive particles at the workpiece at high velocity, thus grinding the workpiece to the shape of the tool.

The abrasives used in USM are aluminum oxide, silicon carbide, and boron carbide. Boron carbide cuts fastest and is the preferred abrasive despite its high cost. Grain sizes of 200 to 400 mesh are used for rough cutting, and sizes of 600 to 1000 mesh are used for finish cuts.

The accuracy obtained in C1SM is about 0.02 mm, with 0.006 mm possible when using the finest grain sizes. The surface finish varies directly with the abrasive grain size used, ranging from 0.75 μm for 100 grit to 0.18 μm for 800 grit.

Tool wear is high in USM, due to the abrasive cutting action. One or more roughing tools and a finishing tool are usually required for each job. Tools made of cold-rolled steel or stainless steel provide the best wear ratios.

USM tools are brazed or soldered to a stainless steel or Monel metal toolholder. The toolholder size and shape must be matched to the machining task to produce the desired resonance and resultant tool movement.

A major advantage of USM is that it can machine materials that cannot conduct electricity and which, therefore, cannot be machined by EDM or ECM. Glass, ceramics and precious and semi-precious stones are examples of nonconducting materials easily machined by USM. The USM process is also valued for its ability to machine tough alloys, hardened steels, and carbides. In addition, soft materials such as plastics and graphite may be cut as easily as hard materials.

The principal disadvantages of USM are low rates of metal removal and high tooling and equipment costs.

Electron beam machining (EBM) is accomplished by focusing a high-speed beam of electrons on the workpiece. The electron beam moves at more than half the speed of light. When it strikes the workpiece surface, its energy is transformed into heat sufficient to vaporize any known material. The amount of material removal, however, is very small.

EBM is mainly used for drilling very small holes and cutting narrow slots in difficult-to-machine materials up to 6 mm thick. Holes as small as 0.01 mm and slots as narrow as 0.025 mm can be made in any material.

EBM is most efficient when done in a "hard" (near-perfect) vacuum. This permits electron beams of full power as narrow as 0.025 mm to be directed to precise locations and focused on spots equally small. At any given location, the beam may be deflected into various patterns within a 6 mm square by magnetic deflection coils. This feature allows (1) the drilling of closely spaced multiple hole patterns from a single location, (2) the drilling of holes of various sizes and shapes, and (3) the cutting of slots of various widths and shapes.

Holes or slots only a few hundredths of a millimeter in size are cut by focusing the electron beam. Larger holes may be cut by **trepanning** (moving the beam in a circular pattern) or by moving the beam off center and rotating the workpiece. Wider slots are made by moving the beam in a small circular path at the same time it is moved along the path of the desired slot.

The disadvantages of the EBM process include the need for skilled operators, high equipment costs, slow cycle times, and limits on workpiece size due to the size of the vacuum chamber available. The process also generates X-rays, thus requiring X-ray shielding of the work area. EBM uses the same equipment as electron beam welding (EBW), but the power settings for the two processes differ.

The energy source for **laser beam machining (LBM)** is a highly concentrated beam of light. **(Laser** is an acronym for **Light Amplification** by **Stimulated Emission** of **Radiation).** When the beam is focused to a small spot, its power density is raised to produce sufficient heat to vaporize any material. However, the rate of metal removal is very small, which limits the use of lasers to hole-drilling and cutting operations in relatively thin materials.

Two types of lasers are now in common use: (1) **solid lasers,** which are capable only of providing short bursts of power, and (2) **gas lasers,** which produce a continuous laser beam.

The central part of the system is a special glass rod, which is known as the lasing **medium.** One end of this rod has a reflective coating. The other end is partially coated. A low-intensity lamp flashes light into the rod. The light reflects between the rod ends and builds up intensity. When it reaches the necessary intensity, the light escapes through the partially coated end.

Since solid lasers are limited to short bursts of power, they are best suited to hole drilling operations or to spot welding and spot heat-treating. Laser-drilled holes are slightly tapered, but have clean edges with little spatter. The surrounding heat-affected zone is slight. The power source can be precisely controlled, thus permitting precise control of hole sizes. Tolerances of ± 3 μm are possible.

It is claimed that laser drilling is the least expensive way to drill holes up to 0.5 mm diameter in thin, flat material.

For holes that enter on slanted or rounded surfaces, and for holes in difficult-to-reach spots, laser drilling is economical for diameters up to 1.25 mm.

At present, carbon dioxide (CO_2) gas lasers are most efficient for converting electricity into laser power. Gas lasers operate in basically the same way as solid lasers, except that a gas serves as the lasing medium and can provide a continuous laser beam. This feature makes gas lasers best suited to continuous cutting, welding, or heat-treating operations.

Computer-controlled cutting systems that use oxygen to boost the heat of the laser beam are now in service. They can make fast, clean cuts in metals and ceramics up to 10 mm thick and in nonmetals, such as plastics and wood, up to 25 mm thick. These systems are also used for partial cutting operations, such as scribing and engraving, and for heat treating and welding. While the initial equipment cost is high, low operating costs and high productivity provide a quick return on investment.

Miscellaneous Metal Machining Processes

Plasma arc machining (PAM) is a high-temperature flame-cutting process. It is used mainly for profile-cutting of stainless steel, aluminum, and other metals that cannot be cut with oxyacetylene torches.

Abrasive jet machining (AJM) uses abrasive particles propelled by a high-velocity stream of air as the cutting tool. The stream of abrasive particles bombards the workpiece at nearly the speed of sound, but since the abrasive particles are very small, material removal is also very slow.

The abrasive particles used vary from less than 10 μm to more than 50 μm in diameter. Aluminum oxide and silicon carbide abrasives are most commonly used.

AJM is chiefly used for cleaning and deburring operations, etching of glass and ceramic materials, and trimming of electrical resistors. AJM is also used for scribing and cutting hard, brittle semiconductor materials. Accurate cuts as narrow as 0.127 mm are possible.

Abrasive flow machining (AFM) is also known as **abrasive flow deburring.** It is mainly used for deburring, rounding sharp edges, and surface polishing. The process involves pumping an abrasive slurry back and forth across the surfaces or edges to be machined. The work must be fixtured to restrict the abrasive flow to where machining is required. The fixture surfaces exposed to the abrasive are provided with wear-resistant coatings to prolong their useful life. Aluminum oxide and silicon carbide abrasives of 20 to 60 grit are commonly used in AFM. The viscosity of the abrasive slurry must be adjusted to obtain the desired velocity and, therefore, the cutting rate through a given size hole. In many cases, AFM is the only way of deburring and finishing holes and surfaces in part interiors.

Chapter 24. The Basing and Methods of Holding Workpiece

24.1. The Basing

The **basing** is the giving to a blank the certain position before machining. The **fastening** (**holding**) of the blank is fixing of basing, it should not break an achievement position of the blank.

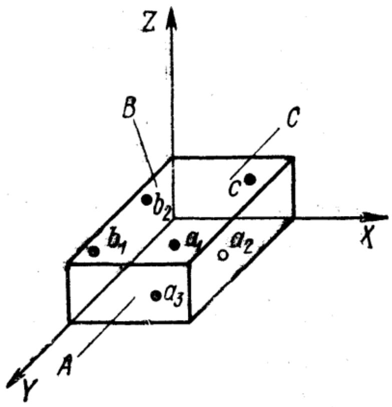
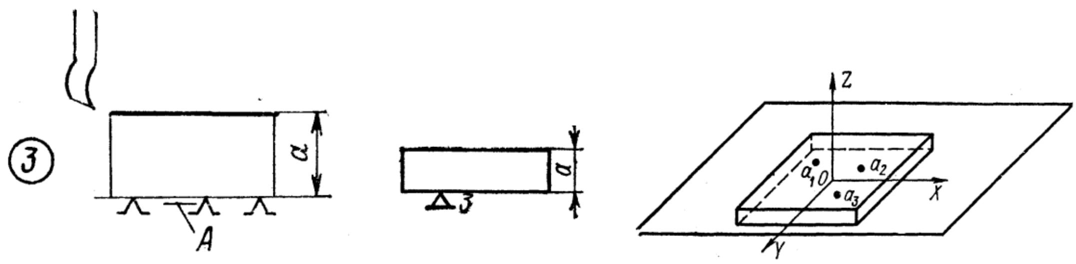


Fig. 24-1. Basing of the blank.

Generally it is necessary to deprive the blank 6 degrees of freedom to give strictly certain position: 3 degrees of freedom on coordinates X, Y, Z (certain position along axes X, Y, Z) and 3 freedom degrees of turn corners concerning axes OX, OY, OZ (Fig. 24-1). At manufacturing a detail it happens enough to deprive one only of some degrees of freedom. Each connection depriving the blank one degree of freedom, can be submitted as a point of contact of preparation



A B C

Fig. 24-2. The basic base. A - the scheme of basing with matching each point of contact; B – the scheme of basing with matching quantity points of contact; C - the arrangement of basic points (points of contact).

with the attachment. This connection is designated ⋎ (side view) and ◊ (top view). For reduction of writing labor one mark can be specified only, and near to it the quantity of deprived degrees of freedom is designated (⋎ 3). If the

technologist wishes to specify a type of the attachment, for example, universal 3 - jaw chuck, the mark is designated, on which figure designates chuck jaws quantity:

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The **surfaces of a blank** (workpiece) adjoining with surfaces of the attachment for achievement of basing are called **bases**. The bases have the name depending on quantity of deprived degrees of freedom and their arrangement.

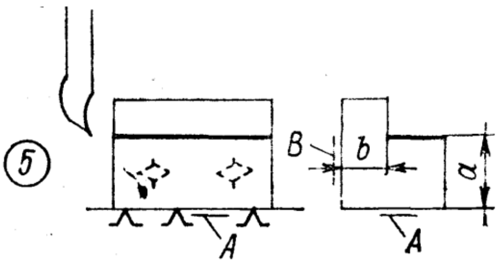


Fig. 24-3. The directing base *B* and the basic base *A*.

1. The **basic base** - detail adjoins to the attachment on a plane (Fig. 24-2). For example, the blank is shaped on a shaper machine on a flat surface, one is held on a magnetic table. It is necessary **to deprive a blank of 3 degrees of freedom**: Z, OX, OY. The discrepancy (uncertainty) of installation of a detail before fastening on axes X, Y and OZ will not affect accuracy of machining on a plane (this machining surface is drawn by a thick line). It is necessary to sustain the size ***a*** (on an axis Z) and **flatness** of a machining surface concerning a basing surface *A* (turn corners concerning axes OX, OY).

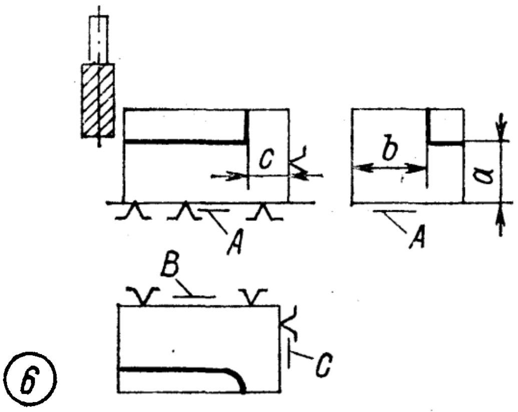


Fig. 24-4. The persistent base *C*, the directing base *B* and the basic base *A*.

2. The **directing base** - detail adjoins to the attachment on **two** remote from each other **points** lying on one line. For example, the shoulder of a workpiece is shaped on a shaper machine (Fig. 24-3). The blank is fastened in a machine vise. It is necessary **to deprive** a detail of three degrees of freedom (Z, OX, OY) on the plane *A* (to supply the size ***b*** and **flatness** of a machining surface concerning a basing surface *A*) and

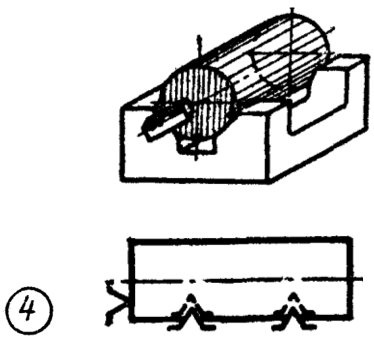


Fig. 24-5. The basing on the prism (the double directing base.). The detail is deprived **4** degrees of freedom on surfaces of the prism and 1 – by the persistent on the left end of the shaft.

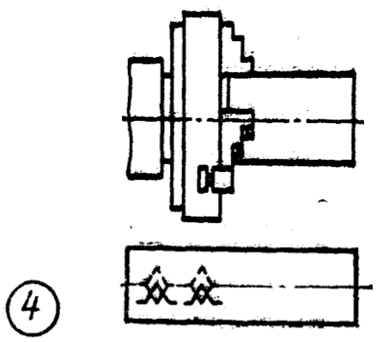


Fig. 24-6. The double directing base. The basing in the universal 3-jaw chuck.

two on the plane *B*, that the shoulder was parallel one of the parties of the workpiece: Y (to supply the size ***b***) and OZ (that the shoulder was parallel one of the parties of a detail).

3. The **persistent base** - detail adjoins to the adaptation in **one point**. For example, the indistinct groove of a blank is grinded on a plane machine tool, the blank is fastened on a magnetic table. It is necessary to deprive a detail 5 degrees of freedom: three degrees of freedom on a plane (Z, OX, OY), two on a direction (Y, OZ) and **one for maintenance of the size** *c* (Fig. 24-4).
4. The **double directing base** - detail adjoins to the adaptation on **two planes** located under a corner to each other (basing on the **prism**, Fig. 24-5, or **in the universal 3-jaw chuck** (Fig. 24-6) (or on the **mandrel**). It is necessary to deprive a detail **4 degrees** of freedom: two on a direction (Y, OZ) and two too on a direction (Z, OY).

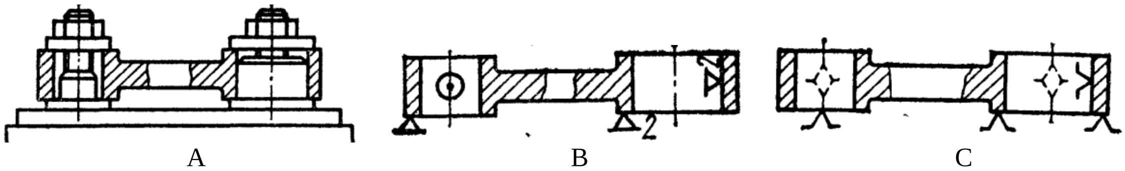


Fig. 24-7. The basing on two holes. A – the cross section of the attachment; B - the scheme of basing with matching quantity points of contact; C – the scheme of basing with matching each point of contact.

5. The **basing on two holes** (Fig. 24-7 A). This basing deprives **4 degrees of freedom** at installation of long blank hole (length more than 10 mm or more than 5 diameters) on a complete long finger (double directing base) **and 1 degree of freedom** at basing in addition one hole on the cut off finger (persistent base), Fig. 24-7 B. At basing on **short fingers** (or thin blank- plate) the blank loses **two and one degree of freedom** accordingly. For more complete definiteness of basing it is necessary to deprive the blank 3 degrees of freedom (on a plane).

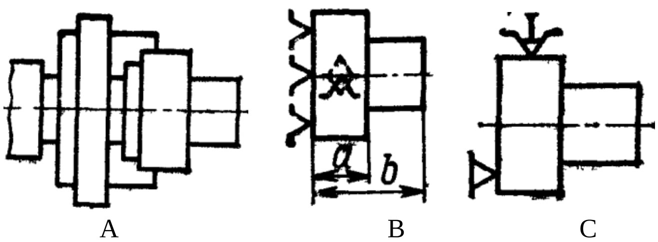


Fig. 24-8. The basing of a disk in the universal 3-jaw chuck for the external surface. A – the front view of the attachment; B - the scheme of basing with matching quantity points of contact; C – the scheme of basing with matching quantity of jaws.

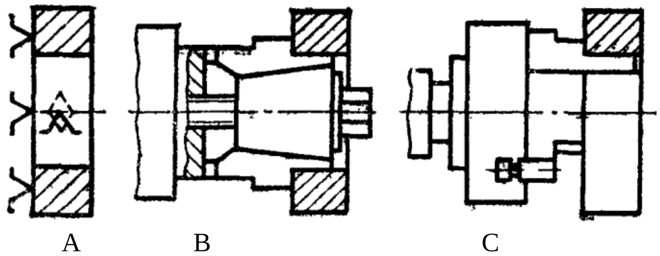
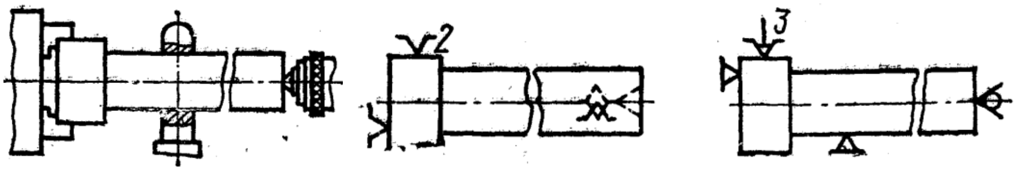


Fig. 24-9. The scheme of basing (A) of the disk on the mandrel (B) and in the universal 3-jaw chuck (C) for the internal surface.

6. The **basing of a disk** in the universal 3-jaw chuck (Fig. 24-8 A, Fig. 24-9 C) deprives a detail of 2 degrees of freedom on

periphery of a disk (Z, Y) and 3 degrees of freedom on an end face (X, OZ, OY), Fig. 24-8 B, C; Fig. 24-9 B, C.

7. The **basing of the long** shaft in the universal 3-jaw chuck and in addition dead centre for centre hole (Fig. 24-10 A) deprives a detail 2 degrees of freedom on periphery of the shaft in universal 3-jaw chuck (Z, Y) and 2 degrees of freedom on centre hole (OZ, OY), Fig. 24-10 C.



A B C

Fig. 24-10. The basing of the long shaft in the universal 3-jaw chuck and in the dead centre for centre hole. A – the front view of the attachment with the steady rest; B - the scheme of basing with matching quantity points of contact; C – the scheme of basing with matching quantity of jaws.

8. The **basing of the shaft in centers** (Fig. 24-11 A) deprives a detail 3 degrees of freedom by the forward centre (it is fixed in a spindle and does not move along axis OX) on left centre hole (X, Z, Y) and 2 degrees of freedom by the dead centre (move together with a tailstock spindle along axis OX) on right center hole (OZ, OY), Fig. 24-11 B, C, D.

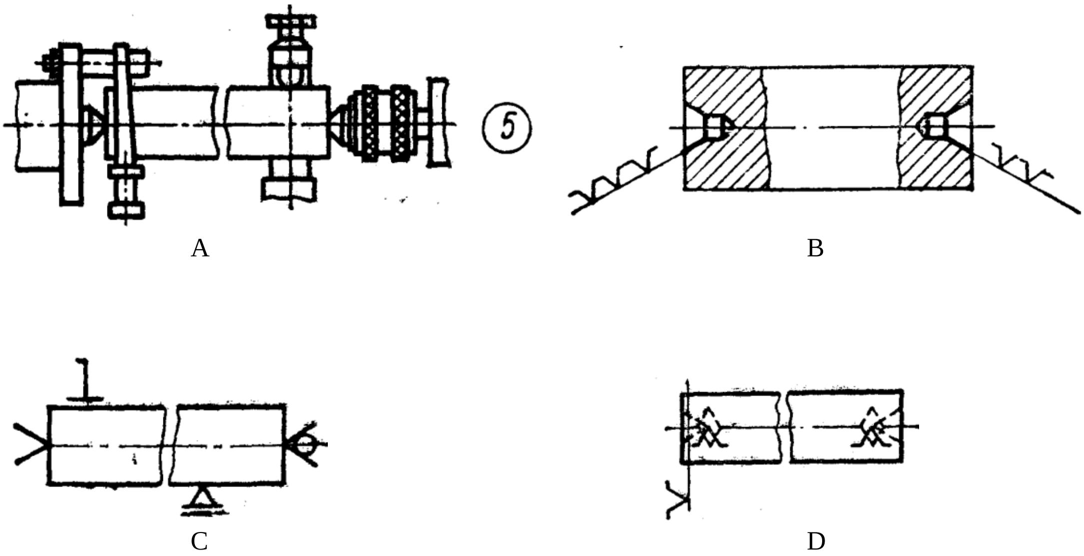


Fig. 24-11. The basing of the long shaft in centers. A – the front view of the attachment with the steady rest; B - the scheme of basing with matching each point of contact with out addition of the steady rest contact point; C – the scheme of basing with matching feature of the attachment design; D - the scheme of basing with matching each point of contact with out addition of the steady rest contact point.

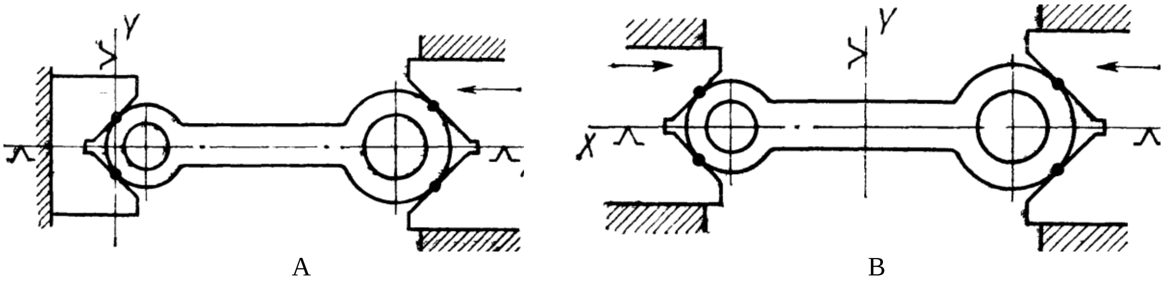


Fig. 24-12. The basing of a rod between 2 prisms. A – the left prism is a stationary; B – two selfcentering prisms.

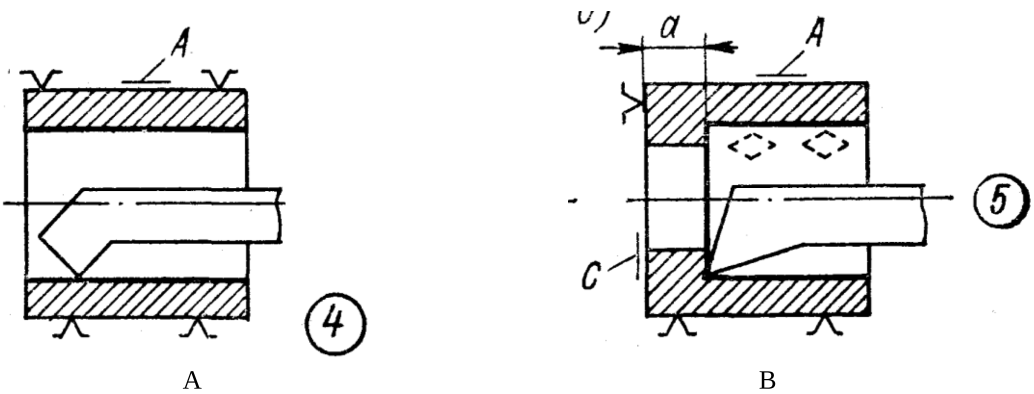


Fig. 24-13. The basing of a sleeve in the universal 3-jaw chuck for the external surface.
A – the through hole turning; B - the step hole turning.

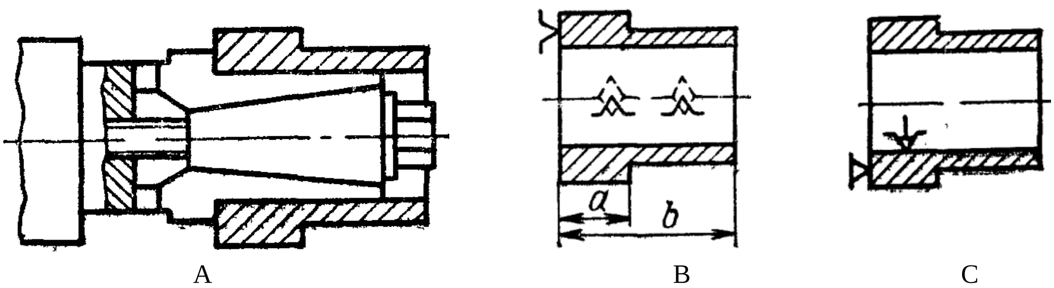
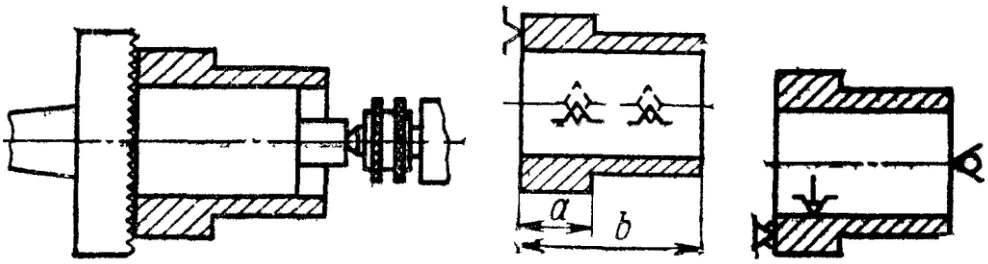
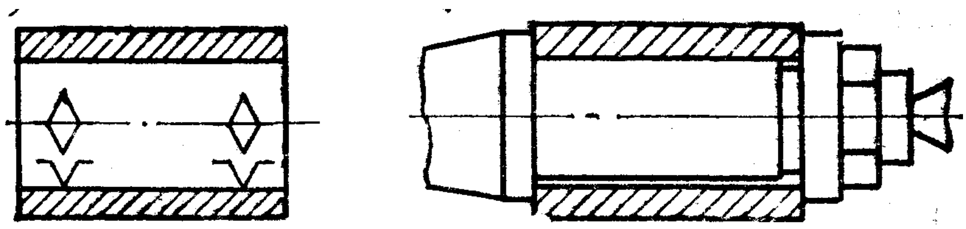


Fig. 24-14. The basing of a sleeve on the selfcentering mandrel, type 1. A – the cross section of the attachment; B - the scheme of basing with matching quantity points of contact; C – the scheme of basing with matching each point of contact.



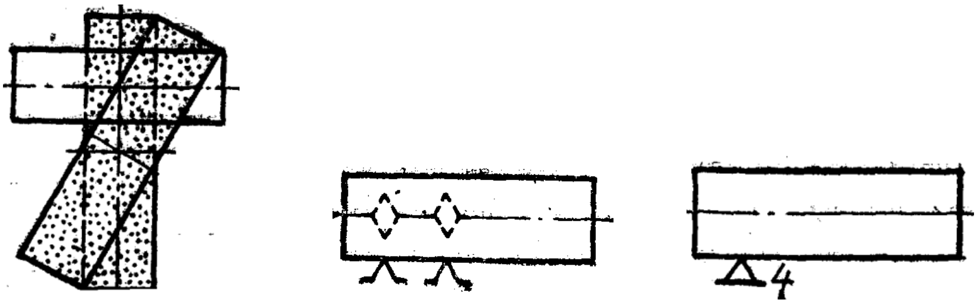
A B C

Fig. 24-15. The basing of a sleeve on the selfcentering mandrel, type 2. . A – the cross section of the attachment; B - the scheme of basing with matching each point of contact; C –. the scheme of basing with matching quantity points of contact and feature of the attachment design.



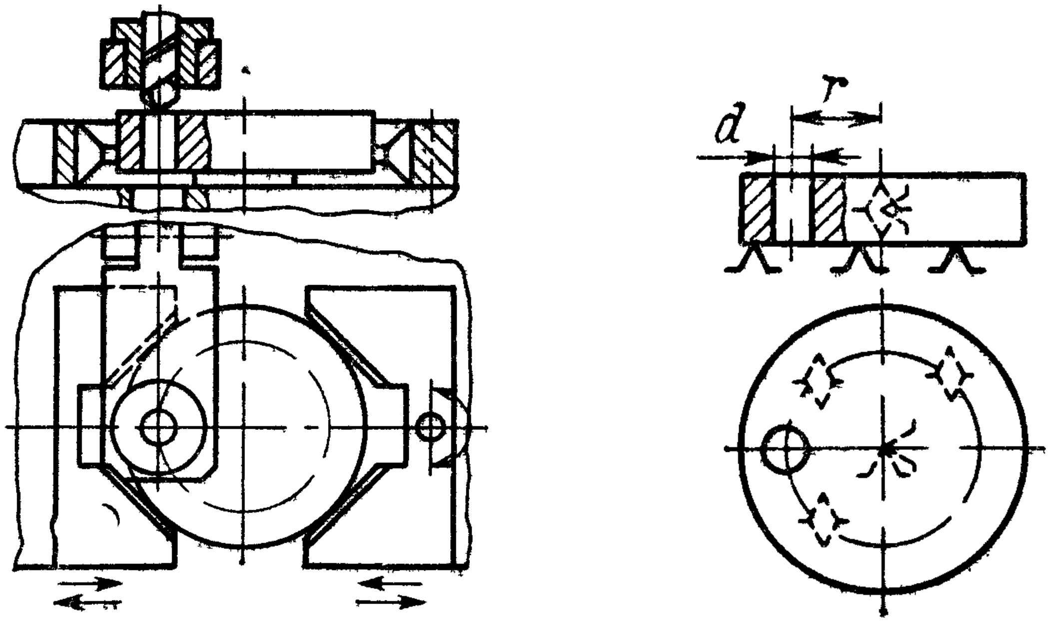
A B

Fig. 24-16. The basing of a sleeve on the non selfcentering mandrel, type 1. A – the scheme of basing with matching each point of contact; B - the cross section of the attachment.



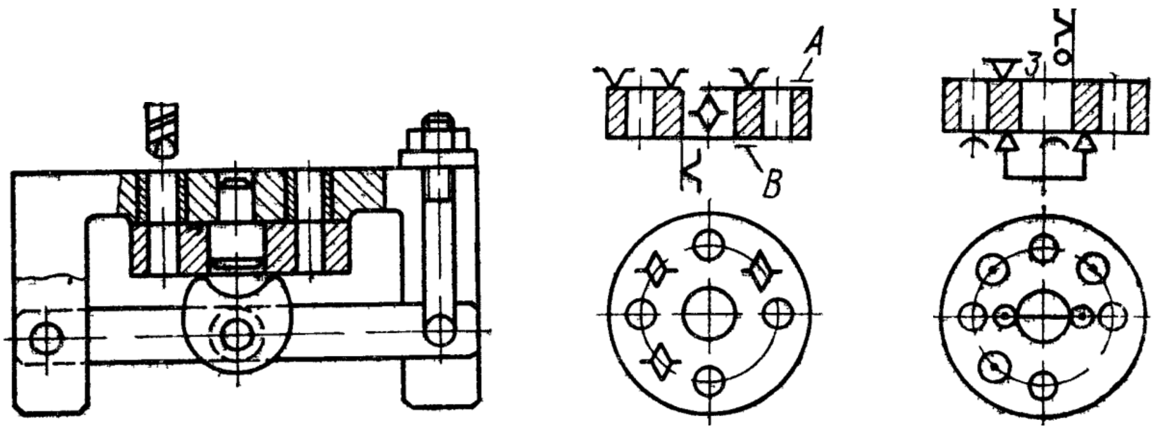
A B C

Fig. 24-17. The basing of the shaft centerless grinding. A – the front view of the machining; B - the scheme of basing with matching each point of contact; C –. the scheme of basing with matching quantity points of contact



A B

Fig. 24-18. The hole drilling of a disk through of drill jig conductor. The basing of a disk between 2 selfcentering prisms. . A – the cross section of the attachment; B - the scheme of basing with matching each point of contact



A B C

Fig. 24-19. The hole drilling of a disk through of drill jig conductor. The basing of a disk on the self installation basic. . A – the cross section of the attachment; B - the scheme of basing with matching each point of contact; C –. the scheme of basing with matching quantity points of contact and feature of the attachment design.

Table 24-1. Conditional designations of support, clips and adjusting devices

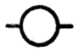
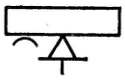
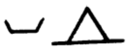
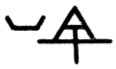
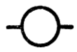
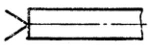
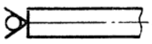
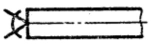
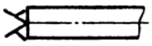
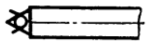
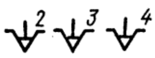
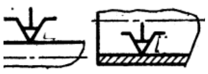
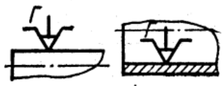
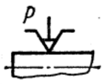
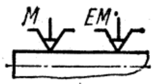
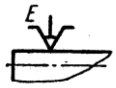
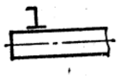
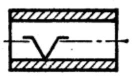
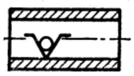
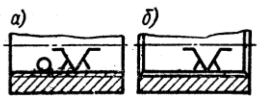
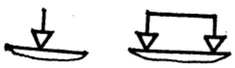
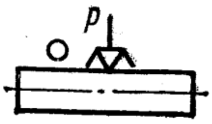
№	The name	The conditional designation		
		The front view	The plan view	
			The top view	The bottom view
1	2	3	4	5
1	A motionless support (a steady rest)			
2	A mobile support (a follow rest)			
3	A floating support (a floating rest)			
4	An adjustable rest			
5	An adjustable rest with a spherical convex working surface		–	–
6	A steady rest with a prism working surface			
7	A follow rest (clip) with a prism working surface			
8	A motionless smooth center (a dead center)		–	–
9	The rotating center (live center)		–	–
10	The floating center		–	–
11	A rifled centre		–	–
12	The rotating opposite rifled center (a rifled bell center)		–	–
13	Two- three- (universal) and four-jaw chucks with a mechanical clip		–	–
14	Chucks and collet chucks (selfcentering mandrels)		–	–

Table 24-2. Conditional designations of support, clips and adjusting devices

№	The name	The conditional designation (the front view)
1	2	3
1	Chucks and mandrels with a hydrauplust (selfcentering) clip	
2	Chucks with an air clip	
3	Hydraulic chucks	
4	Magnetic and electrical magnetic chucks	
5	Electrical clips and chucks	
6	Lathe dogs and lathe dog chucks	
7	A steady rest	
8	A follow rest	
9	A smooth cylindrical mandrel (non selfcentering)	
10	A bearing cylindrical mandrel (non selfcentering)	
11	Threaded (a) and slotted (b) cylindrical mandrel (non selfcentering)	
12	Single and double blocked clips	
13	Air rifled cylindrical clip	

24.2. Methods of Holding Workpiece

24.2.1. Holding Workpiece in the Lathe

Holding Workpiece in the Lathe. Several methods are available and the choice of method will depend on the nature of the work itself and on the operation to be performed on it.

Between Centers. — This is a widely used method, particularly in engine lathe work. Centre holes are drilled in the end of the workpiece (the **work**) by means of special "center drills"; the operation may be done in an ordinary drilling machine, in a special centering machine or in the lathe itself. The work is then supported on two "centers", one of which is carried by the lathe spindle and the other by the tailstock poppet. These centers are made of tool steel, hardened and tempered, and the portion *A* is made a standard taper to fit corresponding taper holes in the headstock spindle and tailstock poppet, an adapter being generally necessary in the first position. The portion *B* is ground to the proper included angle which is generally 60 degrees but may be 75 degrees. Flats may be provided to enable a spanner to be used to remove the centers. The center carried by spindle is called the "live" center because it rotates; it is sometime ground true on the surface *B* while it is in position in the spindle, a small motor-driven grinding wheel being mounted in the tool post for that purpose, it then generally carries a mark to enable it to be put into the spindle always in the same position. The center carried by the tailstock poppet is called the "dead" center. Because of the clearance holes the work does not bear on the extreme points of the centers this is important because otherwise the positioning of the work will be uncertain. The size of the center hole must be suitably proportioned to the weight of the job and the size of cut to be taken.

In order to drive the work when it is mounted between centers a "driving carrier" is secured to its left-hand end. This carrier bears against a driving pin that projects from a driving plate screwed on to the spindle nose.

This method of holding work has the advantage that the work can be removed from the lathe as often as may be desired and on replacement it will always "run true", that is, it will rotate about the same axis as before. Similarly the work may be transferred from the lathe to, say, a grinding machine and will again run true. The chief drawbacks of the method are that it is impossible to drill a hole up end of the work; it is not suitable for castings and forgings except very simple ones; and lastly, in order to machine the whole length of a bar, the bar must be turned end for end after one end has been machined.

The axial adjustment of the tailstock center must be carefully made, since any slackness will result in untrue work and, possibly, broken tools, while too light an adjustment will cause the dead centre to run hot and, possibly, to seize. The poppet must be readjusted from time to time during the progress of the work in order to take up any slackness due to wear and at the commencement, and at intervals during the progress of the work, a little oil or grease must be applied to the dead center. For heavy work ball bearing live centers are frequently used in the tailstock.

On a Mandrel. — The use of a mandrel enables a piece of work that has a hole through its center to be supported between centers. A mandrel is a bar with center holes at each end whose surface is ground true to those centers. The bar is nearly cylindrical but has a very slight taper and its diameter to the middle of its length must be equal to that of the hole in the work to be supported on it. The mandrel is driven into the work by means of a lead hammer and friction is relied on to drive the work, the mandrel being driven by a carrier in the ordinary way. Mandrels may be hardened or left soft and are frequently turned up from a piece of bar as required. Clearly the use of a mandrel enables the outside of a piece of work to be turned concentric with the inside and in general such work would have the hole finished first and the outside finished on a mandrel subsequently. An allied method is to grip a piece of bar in a chuck and to turn it so that the work can just be forced on to it; the work is then turned as if it were on a mandrel. Clearly the bar must not be removed from the chuck until all the pieces of work have been machined. The bar may be screwed on its outer surface if it is required to carry work having a screwed hole.

In a Chuck. — This method of holding work is of very great importance since it is almost universal with capstan and turret lathes and automatic screwing machines and is also widely used with engine lathes. Briefly, a chuck is a vice adapted to be carried on the nose of the lathe spindle. Chucks are of three main types, namely, **independent jaw chucks**, **concentric** or **self-centering chucks** and **collet chucks**. Independent jaw chucks usually have four jaws, the jaws are carried in radial slots in the chuck body and can be adjusted in and out independently by means of screws operated by a chuck "key". The body of the chuck is provided with a screwed hole to fit the spindle nose of the lathe. The concentric chuck usually has three jaws and these are all moved in or out together by means of cams, a scroll (this is a disc with a spiral groove cut on it), or other mechanism; consequently a cylindrical piece of work when held in such a chuck will automatically be centered so that its axis coincides with that of the chuck and thus with the spindle axis. Clearly the concentric chuck is unsuitable (unless special jaws are fitted) for irregular shaped articles; for these the independent jaw chuck must be used.

On a Face Plate. — If the work to be bored is irregular in shape, it may be impossible to set it in a chuck in a position in which the hole could be bored. Such irregular pieces must be fastened to a large face plate that has been put on the lathe in place of a chuck.

A piece of work may be fastened to a face plate by use of bolts, clamps and blockings, in a position for boring the large hole by the use of the angle plate. This plate is first bolted to the face plate, and the work is then fastened to the angle plate.

In each of the above cases, if the bulk of the work or angle plate is to one side of the center, it is advisable to fasten a counterweight to the opposite side of the face plate. If it is not done, the face plate may be so much out of balance as to cause undue vibration in the whole machine and possibly damage to the bearings.

24.2.2. Holding Workpiece on Others Machines

When **drilling**, there is a tendency for the work to rotate. This may be avoided by the use of pins or clamps fastened on the drill-press tables At times it may be necessary to clamp the work to the table securely. For holding many shapes of work, a vise similar to that used on the milling machine is used. The vise "floats" on the drill-press table but is kept from rotating by pins or stops on the table top.

Not all work to be drilled is laid out. When a number of the same pieces are to be drilled in the same location a drill jig is used. A **drill jig** is a device for holding the work and guiding the tool so that each piece will be drilled in the same location and will thus be interchangeable with every other piece. Drill jigs may be simple plates or they may entirely enclose the work as in the case of the **box jig**. In such a jig the work is held in place in the same relative position each time by set screws or other holding devices. Hardened steel bushings guide the drill to the correct location on the work.

Work is held on a **milling machine** in a vise, clamped in a fixture, or fastened directly to the milling machine table. Whatever method is used, the work must be securely held against slipping or moving, as movement of the work would break cutters as well as cause damage to itself. Small work may be most easily held in a vise that has been bolted to the table. When the work is large or irregular in shape and cannot be held in a vise, it may be clamped to the table by using bolts and clamps in the same manner that work is held on the planer table. When there is a number of the same part to be milled, a special holding device or fixture is used.

Shaper work is usually held in a vise that is bolted to the machine table. Large work may be bolted directly on the table. The majority of shaper work, however, may be held in the vise. The work is set on a parallel block so that the top face is level and true with the top face of the vise but higher than it. Copper or brass strips called **false jaws** are frequently put between the work and the vise jaws to prevent the rough casting from bruising or roughening them. Whenever possible the work should be held in the vise so that the direction of cut is perpendicular to the jaws. In this way the maximum backing against the pressure of the cut is secured and the work cannot slip with the cut.

When holding irregular-shaped work that might have a tendency to move under the cut, equalizers are frequently used. The equalizer is made from a piece of flat steel about 12 mm thick, 35 mm wide and 100 mm long, bent lengthwise.

When shaping cast iron with a heavy cut, the tool will break the metal off at the end of the cut and leave a rough ragged edge. It is good practice to avoid such difficulty by beveling the end of the work. The bevel should be cut as deep as the intended cut and may be produced with a chisel or by filing.

The **planer** is the most satisfactory tool for large or heavy flat work. The work may either be held in a vise or clamped directly onto the planer table. The latter case is the more common. The planer table is fitted with *T* slots its entire length and has a number of holes drilled at regular intervals in its top surface. The holes and *T* slots provide a means for attaching clamps and other holding devices to the table to hold the work.

Plain clamps are simply steel blocks longer than wide with a hole through them. In some cases **special finger clamps** are used.

If it is undesirable to drill holes in the work, it is possible to hold it by the use of screw pins set in the holes in the planer table, on the two sides of the work, two or more pins on each side.

Thin pieces of work may be held on the planer table by using screw pins and "**toe dogs**". The work is held against a back block, which has been fastened to the planer table, by the toe dogs, which are tightened against the work by tightening the screws.

Work is often sprung or bent when it is being fastened to the planer table, by **tightening clamps** too tight or by setting clamps over unsupported parts. Packing pieces of thin sheet metal or paper or iron wedges placed under the work to provide rigid support directly under the clamp will prevent springing the work.

In some cases, when the work is of such shape that there is considerable space between the work and the planer table, a **planer jack** may be used as a support. Jacks are also used to support frail work that might spring or bend from the pressure of the planer tool when taking a cut.

Planer parallels are pieces of metal that have been machined with opposite sides parallel. They are very useful in setting planer work to be machined. They are usually made in pairs, two of exactly the same size. A full set of parallels would consist of a number of pairs of different sizes, widths and thickness.

The commonest method of holding work on the **grinding machine** is by means of a magnetic chuck, this is nothing more than a multipolar magnet whose surface is accurately flat to receive work and which is adapted to be clamped to the machine table. The magnet is usually an electromagnet but, with the development of improved magnet, steels, permanent-magnet magnetic chucks can now be made satisfactorily. The chucks are bolted to the tables of the machines and hold the work by magnetic attraction. In some machines the magnetic chuck is built in as an integral part of the work table. Magnetic chucks are sometimes used on cylindrical grinding machines.

Work that has been held on a magnetic chuck must be demagnetized on a demagnetizing fixture after grinding. Other methods of holding the work are similar to those used in shaping and planing machine practice.

Chapter 25. Sizes Circuits

25.1. Classification of Sizes Circuits

Size circuit is the set of the sizes forming a closed contour and directly participating in the decision of a put task (definition of numerical meaning of one of the sizes, its limiting sizes, necessary accuracy of manufacturing etc.).

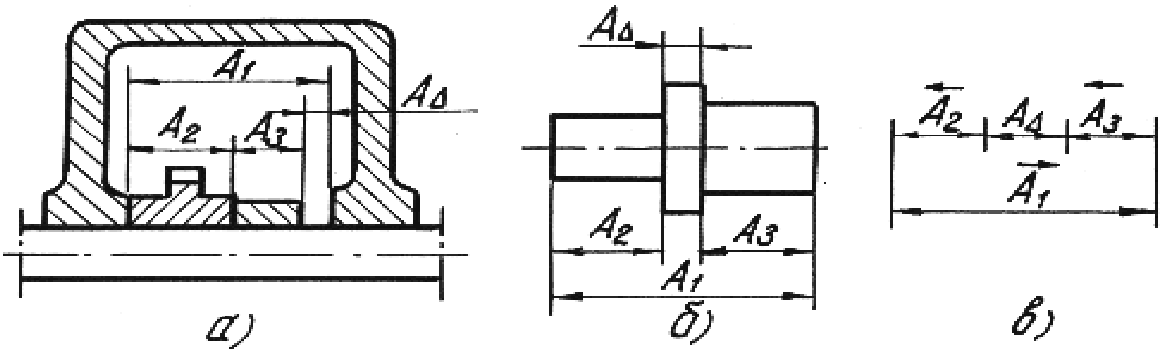


Fig. 25-1. Size circuits: a) assembly design; b) detail design; c) the analysis of character of making parts

Size circuits are be details (in a circuit the sizes only one details enter) and assembly (on the assembly drawing in a circuit there are sizes of different details) (Fig. 25-1). Isolation of a size contour (closed consecutive arrangement of the sizes) - obligatory condition for accounts. The sizes forming a size circuit, name as **parts** of a size circuit.

On a mutual arrangement of parts a size circuits are divided on **flat** and **spatial**. The size circuit is named a **flat**, if its parts are located in one or several parallel planes. The size circuit is named a **spatial**, if its parts not parallel one to another and lay in not parallel planes. The size circuit is named a **linear**, if parts are the linear sizes, and angular, if parts - angular sizes. If the linear sizes in a circuit are parallel each other, such size circuit is named a **one-linear**.

Size circuits is named a **design size circuits**, if they are used for maintenance of accuracy of products at designing. To maintenance of accuracy of manufacturing or its analysis are applied **technological size circuits** expressing changing of detail sizes in process of manufacturing. At indirect measurements are used **measuring size circuits**.

The size circuit consists of **making links** (**parts**) and **one closing**. The size (link) is named a **closing link**, if it is not maintained directly and it is made as a result of performance of all other sizes in a circuit. If for a closing link its extreme allowable sizes (minimal and maximal) are given and it is necessary to execute these requirements, this closing part name an **initial link**, i.e. proceeding from it is necessary to calculate making links of a size circuit.

All making links are divided on increasing and reducing. The **increasing link** is a link, at increase of which size of closing (initial) link will be increased too. Other making parts are accepted constant and there is no difference, to the right or to the left the considered link will be increased - the result will be the same. The **reducing link** is a link, at increase of which size of closing (initial) link will be, on the contrary, decrease.

Any making link near to closing link is usually analyzed, its character (Fig. 25.1) is determined, and designation of a link is marked above a letter by the pointer which is directed to the right for increasing links and to the left - for reducing links. Above other links pointer also are marked on their course. Their direction will prompt character of other links.

The account of a size circuit consists in an establishment of the nominal sizes and their limiting deviations for all parts of a circuit, proceeding from the requirements of a design and technology. Thus distinguish two tasks:

1. Definition of the nominal size and limiting deviations of a closing link for the given nominal sizes and limiting deviations of making parts - **return task** (verifying account).
2. Definition of the limiting deviations of the making links on the given nominal sizes of all making links and given limiting sizes of an initial link - **direct task** (at design account of a size circuit).

25.2. Definition of the limiting sizes of the closing link

For definition of the limiting sizes (minimal and maximal) closing link (return task) the nominal sizes and limiting deviations (upper and lower) of all making parts should be known. The character of all making parts (increasing or reducing part) is defined, the pointer above letter designations of parts are put down. After that the account is made in the following order.

1. Basic (nominal) size of a closing link A_Δ is calculated. This action carries verifying character - basic size should be positive:

$$A_\Delta = \sum_{i=1}^{p} A_{\text{ув } i} - \sum_{i=p+1}^{n} A_{\text{ум } i}, \qquad (25.1)$$

where: p - number of increasing links; n - number of all making links.

2. The maximal size of a closing link is calculated:

$$A_{\Delta max} = \sum_{i=1}^{p} A_{\text{ув max } i} - \sum_{i=p+1}^{n} A_{\text{ум min } i}. \qquad (25.2)$$

If to take into account, that

$$A_{max\ i} = A_i + \Delta^{B}_{A_i}, \qquad (25.3)$$

$$A_{min\ i} = A_i + \Delta^{H}_{A_i}, \qquad (25.4)$$

where A_i – basic size of a link, mm; $\Delta^{B}_{A_i}$ - upper deviation of a link, mm; $\Delta^{H}_{A_i}$ - lower deviation of a link, mm, that it is possible to calculate the upper deviation $\Delta^{B}_{A_\Delta}$ of a closing link:

$$\Delta^{B}_{A_\Delta} = \sum_{i=1}^{p} \Delta^{B}_{A_{ув\ i}} - \sum_{i=p+1}^{n} \Delta^{H}_{A_{ум\ i}} . \qquad (25.5)$$

The minimal size of a closing link is calculated:

$$A_{\Delta min} = \sum_{i=1}^{p} A_{ув\ min\ i} - \sum_{i=p+1}^{n} A_{ум\ max\ i} \qquad (25.6)$$

or a lower deviation of a closing link is:

$$\Delta^{H}_{A_\Delta} = \sum_{i=1}^{p} \Delta^{H}_{A_{ув\ i}} - \sum_{i=p+1}^{n} \Delta^{B}_{A_{ум\ i}} . \qquad (25.7)$$

3. The minimal size of a closing link is calculated:

$$A_{\Delta min} = \sum_{i=1}^{p} A_{ув\ min\ i} - \sum_{i=p+1}^{n} A_{ум\ max\ i} \qquad (25.6)$$

or a lower deviation of a closing link is:

$$\Delta^{H}_{A_\Delta} = \sum_{i=1}^{p} \Delta^{H}_{A_{ув\ i}} - \sum_{i=p+1}^{n} \Delta^{B}_{A_{ум\ i}} . \qquad (25.7)$$

4. If from the formula (25.2) to take away the formula (25.6), we shall receive the formula (25.8) for check of correctness of calculations in view of that $A_{\Delta max} - A_{\Delta min} = T_{A_\Delta}$, where T_{A_Δ} is a tolerance of a closing link:

$$T_{A_\Delta} = \sum_{i=1}^{n} T_{Ai} , \qquad (25.8)$$

i.e. the tolerance of a closing link is equal to the sum of the tolerances of all parts of size circuit. Generally the formula is:

$$\sum T_{Ai} \le T_{A_\Delta} . \qquad (25.9)$$

From the formula (12.9) follows, that for maintenance of the least error of a closing link the size circuit should consist of (in possible) smallest number of parts and each of these parts should have the smallest tolerance (in possible). Therefore order of manufacturing or assembly of details is desirable to make so that the closing link will be a least responsible link (since its error will be greatest).

Example of account of a size circuit concerning a closing link (Fig. 25-2).

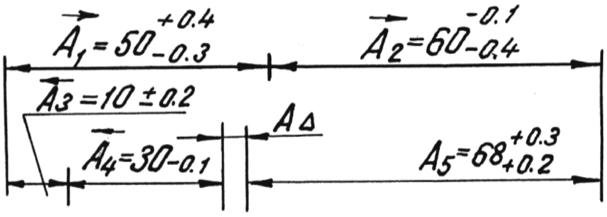


Fig. 25-2. Size circuit

1. We determine the character of a link nearest to a closing link (for example, A_5 is the reducing link). We match by the pointer (for reducing parts it is directed on the left ←), but this pointer is not match in the Fig. 25-2.
2. We determine characters of other parts, go on a course of the pointer and match it above letter designations. The isolation of the size circuit is simultaneously checked.
3. Basic size of a closing link A_Δ is calculated by the formula (25.1):

$$A_\Delta = \sum_{i=1}^{p} A_{\text{ув } i} - \sum_{i=p+1}^{n} A_{\text{ум } i} = (A_1 + A_2) - (A_3 + A_4 + A_5) =$$
$$= (50 + 60) - (10 + 30 + 68) = 110 - 108 = 2\text{мм}.$$

4. We calculate the upper deviation of a closing link by the formula (25.5):

$$\Delta^B_{A_\Delta} = (\Delta^B_{A_1} + \Delta^B_{A_2}) - (\Delta^H_{A_3} + \Delta^H_{A_4} + \Delta^H_{A_5}) =$$
$$= [(+0{,}4) + (-0{,}1)] - [(-0{,}2) + (-0{,}1) + (+0{,}2)] = +03 - (-0{,}1) = +0{,}4\text{мм}.$$

5. We calculate the lower deviation of a closing link by the formula (25.7):

$$\Delta^H_{A_\Delta} = (\Delta^H_{A_1} + \Delta^H_{A_2}) - (\Delta^B_{A_3} + \Delta^B_{A_4} + \Delta^B_{A_5}) =$$
$$= [(-0{,}3) + (-0{,}4)] - [(+0{,}2) + 0 + (+0{,}3)] = -0{,}7 - 0{,}5 = -1{,}2\text{мм}.$$

6. We calculate the tolerance of the closing link:

$$T_{A_\Delta} = \Delta^B_{A_\Delta} - \Delta^H_{A_\Delta} = +0{,}4 - (-1{,}2) = 1{,}6\text{мм}.$$

7. We make check:

$$\sum_{i=1}^{n=s} T_{Ai} = T_{A1} + T_{A2} + T_{A3} + T_{A4} + T_{A5} = 0{,}7 + 0{,}3 + 0{,}4 + 0{,}1 + 0{,}1 = 1{,}6\text{мм}.$$

8. Basic size and limiting deviations of a closing link $A_\Delta = 2^{+0{,}4}_{-1{,}2}$ mm, or more correct formulation is: the limiting sizes of a closing link is changed from $A_{\Delta\ min}$=0.8 mm to $A_{\Delta\ max}$=2.4 mm.

25.3. The Deviations Definition of Making Links for a Known Initial Link

The determine of deviations of making parts for a known initial link (direct task) is possible by several methods: 1) method of the equal tolerances; 2) method of the equal accuracy at complete interchangeability; 3) method of the equal accuracy at incomplete interchangeability.

25.3.1. Method of the Equal Tolerances

At the decision of a task by the method of the equal tolerances supposes, that tolerances of all making links are equal irrespective of numerical value of the link size. According to the formula (25.8) tolerance of a closing link will be equal to product of the tolerances of any link T_A on quantity *n* of making links:

$$T_{A_\Delta} = \sum_{i=1}^{n} T_{Ai} = n \cdot T_A, \qquad (25.10)$$

whence

$$T_A = T_{A_\Delta} / n \quad . \qquad (25.11)$$

When we have found numerical values of tolerances, the deviations of all parts are put down, except for one, for which the upper and lower deviations are calculated by formulas (25.5) and (25.7). This account is necessary that the limiting sizes of a closing link do not leave for given by the designer.

25.3.2. Method of equal accuracy at complete interchangeability

For the decision of the put task it is considered, that at equal accuracy of manufacturing of parts its grades of tolerance will be identical, i.e. factor of accuracy a_n will be same for all making parts.
Tolerance is

$$T_{Aj} = a_n i_{Aj} \ , \qquad (25.12)$$

where a_n – quantity of units of the tolerance (factor of accuracy), dependent only from grade of tolerance and not dependent from the size of a link; i_{Aj} - unit of the tolerance, which numerical value depends only from the size of a link and does not depend from grade of tolerance.

At substitution of the formula (25.12) in the formula (12.8) we receive:

$$T_{A_\Delta} = \sum_{j=1}^{m} T_{Aj} = a_n i_{A1} + a_n i_{A2} + ... + a_n i_{Aj} =$$
$$= a_n (i_{A1} + i_{A2} + ... + i_{Aj}) = a_n \sum_{j=1}^{m} i_{Aj} \ , \qquad (25.13)$$

where *m* is a quantity of making parts in a size circuit.

For the decision of the put task it is considered, that at equal accuracy of manufacturing of parts its grades of tolerance will be identical, i.e. factor of accuracy a_n will be same for all making parts.

Then we calculate factor of accuracy a_n:

$$a_n = T_{A_\Delta} / \sum_{j=1}^{m} i_{Aj} \ . \qquad (25.14)$$

By the formula (25.14) we find factor of accuracy a_n of manufacturing parts, and then grade of tolerance is determined from the tolerance table. Knowing grade of tolerance and basic sizes of parts we find tolerances of all parts, the deviations etc., as for the method of the equal tolerance.

25.3.3. Method of equal accuracy at incomplete interchangeability

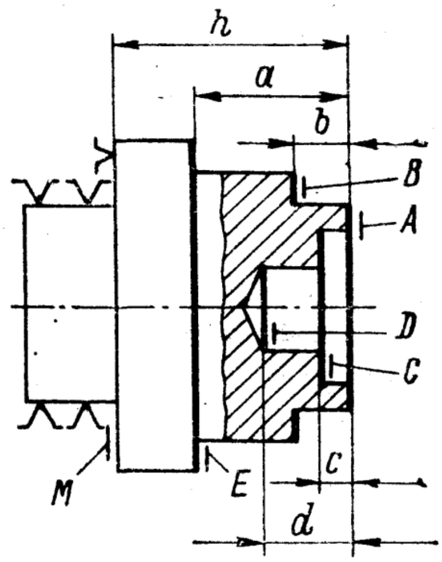


Fig. 25-3. Technological size circuit in accordance with basing.

When we deal with the method of complete interchangeability we take into account the most adverse combinations of the sizes of the size circuit (for example, all increasing parts are made maximal, and all reducing - minimal, or on the contrary). At enough quantity of links (such combination is more 3) this will meet seldom enough, therefore it is possible to take advantage of a rule of summation of sizes verity (square root from the sum of squares). In this case formula (25.14) will look like (when distribution law of sizes verity is the law Gaussian):

$$a_n = T_{A_\Delta} / \sqrt{\sum_{j=1}^{m} i_{Aj}^2} \ . \qquad (12.15)$$

Factor of accuracy a_n calculated by the method of incomplete interchangeability is more than a_n , calculated by the method of complete interchangeability. Therefore grade of tolerance is greater and we can make links of size circuit with less accuracy.

By the formula (25.15) we find factor of accuracy a_n of manufacturing parts, and then grade of tolerance is determined from the tolerance table. Knowing grade of tolerance and basics sizes of parts we find tolerances of all links, the deviations etc., as for the method of the equal tolerance.

Chapter 26. Cut Layer in Machining

Cut layer there is a layer of a material, removed in manufacturing. Its minimal thickness Z_{min} depends on many factors, but basics are:

1. Roughness of a surface received at the **previous** manufacturing (**index i-1**) - $Rz_{\,i-1}$;
2. Thickness of a defective layer of a surface received at the previous manufacturing - $Tdef_{\,i-1}$;
3. Curvature of a surface received at the previous manufacturing - $\rho_{\,i-1}$;
4. Error of basing and fastening received at considered manufacturing (index i) - $\varepsilon_{\,i}$.

If cut layer will be less minimal, the traces from the previous machining will stay, that is not allowable. Cut layer is removed per one cut or several, if the thickness is too large.

Minimal cut layer for considered machining (operation) is defined from the tables or calculated by the formula:

$$Z_{min\,i} = Rz_{\,i-1} + Tdef_{\,i-1} + \rho_{\,i-1} + \varepsilon_{\,i}. \qquad (26.1)$$

Minimal cut layer for rotation surfaces is calculate by the formula:

$$2Z_{min\,i} = 2(Rz_{\,i-1} + Tdef_{\,i-1} + \rho_{\,i-1} + \varepsilon_{\,i}) . \qquad (26.2)$$

Minimal cut layer Z_{min} for **roughing cut** (grade tolerance is 11 – 14) is **2 – 5** mm, for **semifinishing cut** (grade tolerance is 8 – 10) is **0.2 – 0.5** mm, for **finishing cut** (grade tolerance is 6 – 7) is **0.05 – 0.2** mm.

Maximal cut layer for considered manufacturing is calculated by the formula:

$$Z_{max\,i} = Z_{min\,i} + Td_{\,i-1} + Td_{\,i}\,, \qquad (26.3)$$

where $Td_{\,i-1}$ is the tolerance of the surface size for the previous manufacturing, $Td_{\,i}$ is the tolerance of the surface size for the considered manufacturing.

Than depth of cutting is greater, than deformation of a detail and cutting tool is greater, i.e. error of the machining there is greater. Therefore the technological process is made so that the machining was made stage by stage, with each time reducing cut layer and grade tolerance (on 1 - 2 numbers). An example stage by stage of grade tolerance reduction is 14 → 11 → 9 → 7 → 6. Before heat treatment the detail is machined usually with 7 grade tolerance, and after heat treatment such layer of a material is removed to remove heat deformation errors of a detail (usually 0.2 - 0.5 mm, but can be much more for a long and not rigid detail).

The initial blank size is calculated by a method serial cut layer imposing on a ready detail in accordance with an accuracy of manufacturing for each stage (operation). We begin from the end and the intermediate (technological) sizes are written from left to right. For example, the surface manufacturing of a detail consists from **rough** turning (11 grade tolerance, $2Z_{min}$ = 2 mm), **semi finish** turning (9 grade tolerance, $2Z_{min}$ = 0.5 mm) and **finish grinding** (7 grade tolerance,

$2Z_{min}$ = 0.2 mm). The route of manufacturing for the ready detail size 30s7 is written: 32.7 → 30.7h11 → 30.2h9 → 30s7.

$2Z_{min}$ = 2 mm $2Z_{min}$ = 0.5 mm $2Z_{min}$ = 0.2 mm

The initial blank size have to be more than 32.7 mm. If we take into account an accuracy of blank manufacturing 14 grade tolerance (tolerance is 0.62 mm) the initial blank size have to be: 32.7 + 0.62 = 33.32 ≈ 33.4 mm, i.e. d_{blank} = ǿ 33.4h14. To take into account an accuracy of the technological sizes usually technological size of a **shaft is increased** to nearest larger value (30.2h9 → 30.3 h9). Then the route of manufacturing for the ready detail size 30s7 is written:

33.6h14 → 31h11 → 30.4h9 → 30s7.

T_d = 0.62 mm, $2Z_{min}$ = 2 mm. T_d = 0.16 mm, $2Z_{min}$ = 0.5 mm. T_d = 0.062 mm, $2Z_{min}$ = 0.2 mm.

Technological size of a **hole is reduced** to nearest smaller value (29.8H9 → 29.7H9). The route of manufacturing for the ready detail size 30S7 is written:

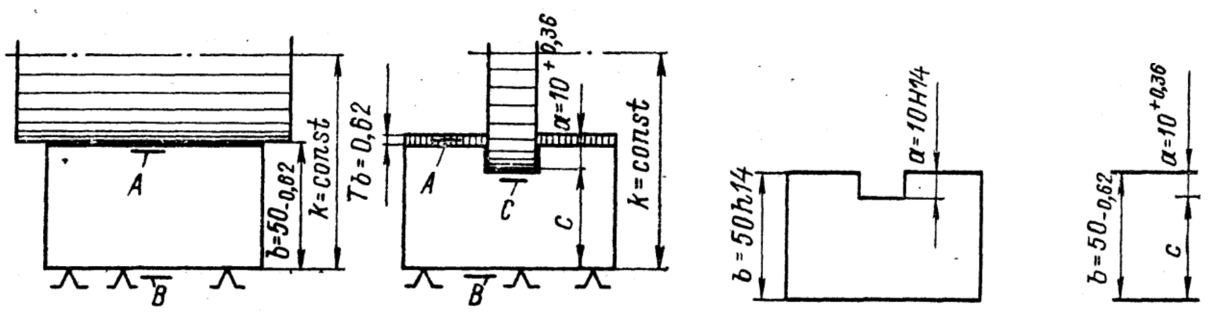
26.6H14 → 29.1H11 → 29.7H9 → 30S7.

T_D = 0.52 mm, $2Z_{min}$ = 2 mm. T_D = 0.13 mm, $2Z_{min}$ = 0.5 mm. T_D = 0.052 mm, $2Z_{min}$ = 0.2 mm.

Connection of a maximal cut layer with a size circuit and basing is shown in Fig. 26-1. Maximal cut layer for considered manufacturing $Z_{max\ a} = Z_{max\ i}$ is calculated by the formula (26.3):

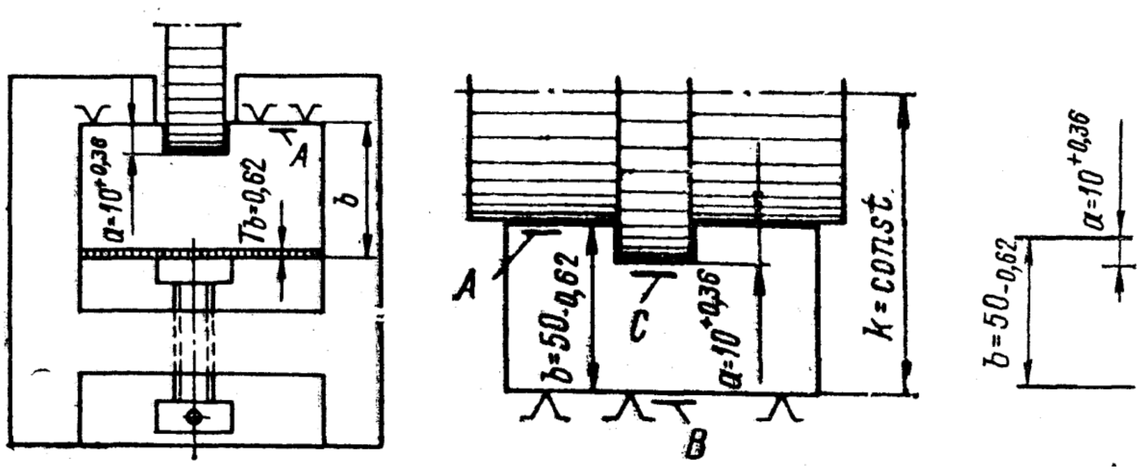
$$Z_{max\ i} = Z_{min\ i} + Td_{\ i-1} + Td_{\ i} = 10 + 0.62 + 0.36 = 10.98 \text{ mm},$$

where $Td_{\ i-1}$ = 0.62 mm is the tolerance of the surface size for the previous manufacturing (T_b) , $Td_{\ i}$ = 0.36 mm is the tolerance of the surface size for the considered manufacturing (T_c).



A B C D

Fig. 26-1. Connection of a cut layer with a size circuit and basing. A – milling of the surface *A* with dimension b=50 mm from the base surface *B*; B - milling of the slot with dimension a=10 mm from the surface *A*; C – the detail design; D - size circuit (size *a* is the closing link).



A B C

Fig. 26-2. Connection size circuit, cut layer and basing. A - milling of the slot with the dimension a=10 mm from the base surface *A*; B – straddle milling of the surface *A* with the dimension b=50 mm from the base surface *B* and the slot with the dimension a=10 mm from the surface *A* by set of mills; C - size circuit (size *a* is obtained directly).

Connection of a maximal cut layer with a size circuit and basing by means of directly machining is shown in the Fig. 26-2. Maximal cut layer is

$Z_{max\ a} = 10 + 0.36 = 10.36$ mm.

Chapter 27. Technological Designing

27.1 The Basic Terms of Technological Designing

The **production** is set of all actions necessary for manufacturing or repair of a made product. The structure of production is:

1. Unloading and storage of materials, blank, semi finished items.
2. Quality control of materials, blank, semi finished items.
3. Transportation of materials and blanks to a place of their subsequent manufacturing.
4. Various kinds of manufacturing (molding, cutting, forging, punching, welding, sawing, turning, milling, drilling, planing, broaching, grinding, gearing, heat treatment, polishing etc.).
5. Quality control after each manufacturing and ready detail.
6. Storage in intermediate warehouses after each manufacturing (if it is necessary).
7. Storage of ready details.
8. Assembly.
9. Coloring.
10. Adjustment and test.
11. Packing.

12. Storage of ready products.
13. Shipment of ready products to the customers.

The **technological process** is a part of production including consecutive change of the sizes, form, appearance or internal properties of a subject of manufacture and their control.

The technological processes are subdivided into processes of mechanical and heat treatment, assembly, control etc. The technological processes of machining are subdivided into **processes of plastic deformation** (forging, punching, rolling, extrusion etc.) and **machining with removal of a shaving** (sawing, turning, milling, drilling, planing, broaching, grinding, gearing, polishing etc.). We shall consider only technological processes of machining with removal of a shaving.

The technological process is divided into operation for organization of manufacture.

The **operation** is the completed part of technological process including all actions, carried out on one workplace, since installation, fastening and finishing stacking of the processed detail in container.

The **technological operation** is a part of technological process carried out continuously on one workplace, above one or several simultaneously machined workpiece or assembled machine, by one or several workers.

The operation consists of one or several settings (to not confuse to installation). The **setting** there is a part of operation including all actions, made at a constant position, concerning the attachment or machine tool.

The setting consists of installation, fastening, machining, taking off the ready workpiece (or reinstallation of a blank).

The **installation** (**basing**) of the blank defines its position relatively an attachment. The **fastening** fixes the achieved basing. The effort of fastening should be sufficient, that the blank was not displaced at machining, but not too large to not damage fixed blank.

The **position** is the fixed situation occupied by invariable fixed machined blank or assembled assembly unit together with the attachment relatively the tool or a motionless part of the equipment, for performance of the certain part of operation.

The **technological transition** is the completed part of technological operation characterized by a constancy of the used tool, modes of cutting and machined surface (or surfaces connected during an assembly).

With reference to conditions of machining the definition of transition can be specified by the following formulation: the **technological transition** is the completed part of technological operation which is carried out above one or several surfaces of a blank, one or several simultaneously working tools without change or at automatic change of modes of operations of the machine tool.

From the given definition follows, that one transition is not only part of operation concerning machining of one simple surface or a shaped surface by the simple or shaped tool, but also simultaneous machining of several surfaces by a complete set of cutting tools (set of mills, multitool machining), and also processing of curve surfaces by the simple tool driven on a contour or the given program (milling of complicated shapes or working profile turbine etc.).

Elementary transition is a part of technological transition which is carried out by one tool, above one site of a surface of machining blank, for one working course without change of mode of operations of the machine tool.

The **cutting stroke** is the completed part of technological transition consisting of unitary moving of the tool concerning preparation, accompanied by change of the form, sizes, quality of a surface and properties of preparation.

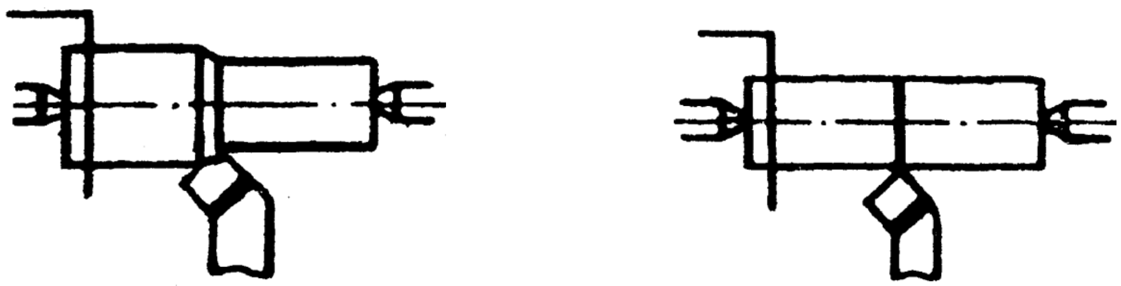
Auxiliary transition is the completed part of technological operation consisting of actions of the man or the equipment, which are not accompanied by change of the form, sizes and roughness of surfaces of a work subject, but are necessary for performance of technological transition. Examples of auxiliary transitions are: installation of a blank, change of the tool etc.

The condition of a continuity of operation means performance of the work without transition to machining of other product. For example, the machining of the step shaft at the centers on the turning machine tool represents one technological operation, if it carry out for two settings in such sequence:

Operation 1:

Setting A – 1) Fix a lathe dog; 2) Mount a blank between centers; 3) Turn off the shaft on one end; 4) Take off the blank.

Setting B – 5) Refix the lathe dog; 6) Mount the blank between centers; 7) Turn off the blank on the other end; 8) Take off the ready workpiece and put it in container.



Setting A **Setting B**

Fig. 27-1.Operation drawings of operation 1.

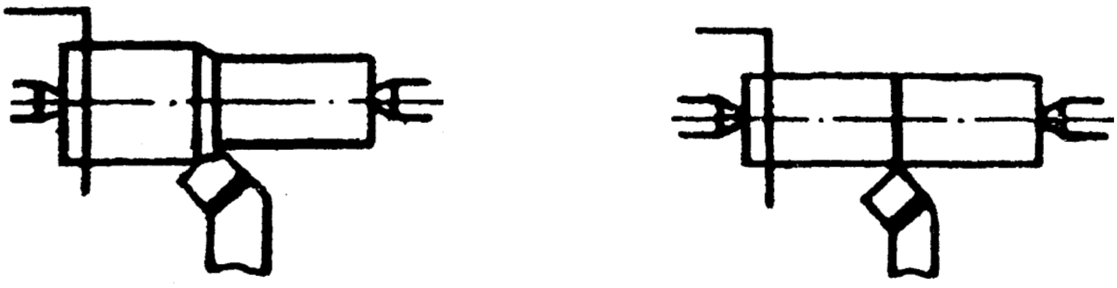
The work, similar on the contents, above the step shaft can be executed and for two operations, but for one setting in each operation, if secondary installation and the processing of the second end of the step shaft will follow not at once after machining the first end, and with a break for machining other blanks of a set (at first all blanks are machined from one end, and then all — from another).

Operation 1:

1) Fix a lathe dog; 2) Mount a blank between centers; 3) Turn off the shaft on one end; 4) Take off the blank and lathe dog, put the processed detail in container.

Operation 2:

1) Fix the lathe dog on the other end of the blank; 2) Mount the blank between centers; 3) Turn off the blank on the other end; 4) Take off the ready workpiece and put it in container.



Operation 1 **Operation 2**

Fig. 27-1.Operation drawings of operation 1and 2.

The given example shows, that structure of operation establish not only on a basis of only technological reasons, but also in view of organizational expediency.

The technological operation is a basic unit of industrial planning and account. On the basis of operations the labor input of products manufacturing is defined and the norms of time and quotation are established; the required quantity of the workers, equipment, attachments and tools, the cost price of manufacturing is calculated; the calendar planning of manufacture is made and the quality surveillance and terms of performance of works is carried out.

27.2. The Basic Principles of Designing of Technological Processes

The designer of technological processes (technologist) projects technological processes, i.e. defines a kind and sequence of performance of processing, model of machine tools, ways of basing and fastening of blanks, used attachments, cutting and measuring tools, modes of cutting, methods of quality control, time for manufacturing a detail. The performance of required quality of manufacturing of a detail requires observance of the certain laws of designing, which have the specificity depending on a type of manufacture, branch, degree of worn out of the equipment etc. The basic principles of designing of technological processes:

1. On the first operation the surfaces should be processed which will be a base at the subsequent manufacturing.

2. On the first and second operations should be rough machined the greatest quantity of surfaces, that on the subsequent processing was not strewed dross on directing of machine tools and it was not necessary to cut off large cut layer.

3. The worn out machine tools are applied to draft operations, exact machine tools - only for fair operations, on which the cutting large cut layer for prevention of the raised(increased) deterioration of machine tools and loss of their accuracy is inadmissible.

4. On the rough operations the rough attachments are usually applied, but it allow reliable to fix a blank, to transfer the large twisting moments and to resist to the large cutting forces at cutting large cut layer (universal chuck, machine vise etc.).

5. It is inadmissible to unite in one operation such kinds of processing, which require applications of different attachments (for example, universal chuck and centers).

6. The operation is required in addition to be divided into operation, instead of several settings, if the sizes of fixed surfaces differ more than 10 mm for prevention of the large moving of attachment working parts, loss of time and increased of wear of the attachment friction parts.

7. The quantity of cutting tools should not exceed number of positions in the toolholder.

8. The quantity of machined surfaces for rough processing should not be more than 10 for prevention of probability of a mistake of the worker.

9. The concentration of technological transitions is applied in individual and small-scale production, and in mass production - on the contrary differentiation (no more than 3 -5).

10. It is inadmissible to use the same cutting tool even with identical geometry for rough and finish processing.

11. The quantity of machined surfaces for finish processing is not desirable more than 1 for reduction of an error of installation by the adjusted size (“on zero”) at processing the following blank.

12. The turn of the toolholder is inadmissible at finish processing because of occurrence of an error of toolholder fastening, one tool therefore is applied only.

13. Warehousing on 5 - 24 hours of blanks after rough processing is necessary for blanks cooling before semifinish and finish processing.

14. The exact attachments (centers, collets etc.) are used only for finish processing.

15. The surfaces requiring exact processing, are processed at the end of technological process for prevention of probability of their damage.

16. The base surfaces should be processed not more roughly 9 grade of tolerance if we use collets.

17. The surfaces of a details requiring of an exact mutual arrangement rather each other should be processed at one setting or with use of exact attachments.

18. The application of several tools is inadmissible at processing on milling or grinding machine tools because of the large time of its change.

19. Rough and semifinish processing of surfaces, is especial of apertures, groove etc., should be executed before hardened.

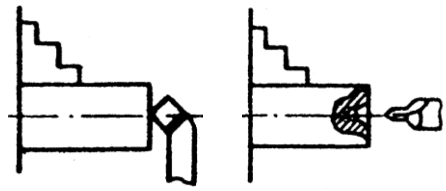
In accordance with these basic principles of designing of technological processes we show the sequence of machining of a shaft with simplification (without dimensions, cutting speeds, feed, time etc.).

Example 1. Technological process of a smooth shaft.

Operation 1:

Setting A

1) Mount a blank in an universal 3-jaw chuck;
2) Turn off the right end of the shaft (side A);
3) Drill a center hole on the side A;



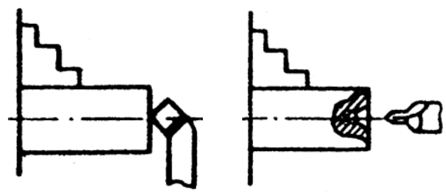
A – transition 2; B – transition 3

Setting A

Fig. 27-1. Operation drawings of setting A of operation 1.

Setting B

4) Remount the blank;
5) Turn off the left end of the shaft (side B);
6) Drill a center hole on the side B;
7) Take off the blank and put the processed detail in container.



A – transition 5; B – transition 6

Setting B

Fig. 27-2. Operation drawings of setting B of operation 1.

Operation 2:

1) Fix a lathe dog;
2) Mount a blank between centers;
3) Turn off the shaft on the side A;
4) Take off the blank and lathe dog, put the processed detail in container.

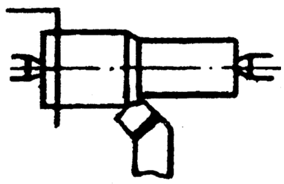


Fig. 27-3. Operation drawing of operation 2, transition 3.

Operation 3:

1) Fix a lathe dog;
2) Mount a blank between centers;
3) Turn off the shaft on the side B;
4) Take off the blank and lathe dog, put the processed detail in container.

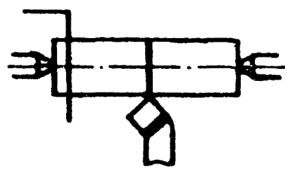


Fig. 27-4. Operation drawing of operation 3, transition 3.

Operation 4:
1) Fix a lathe dog;
2) Mount a blank between centers;
3)Turn off the shaft on the side A definitively;
4) Take off the blank and lathe dog,
put the processed detail in container.

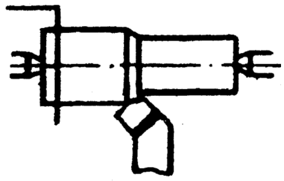


Fig. 27-5. Operation drawing of operation 4, transition 3.

Operation 5:
1) Fix a lathe dog;
2) Mount a blank between centers;
3)Turn off the shaft on the side B definitively;
4) Take off the blank and lathe dog,
put the processed detail in container.

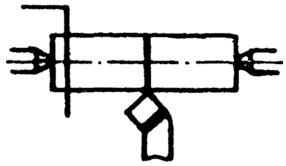


Fig. 27-6. Operation drawing of operation 5, transition 3.

Example 2. Technological process of a stepped shaft.

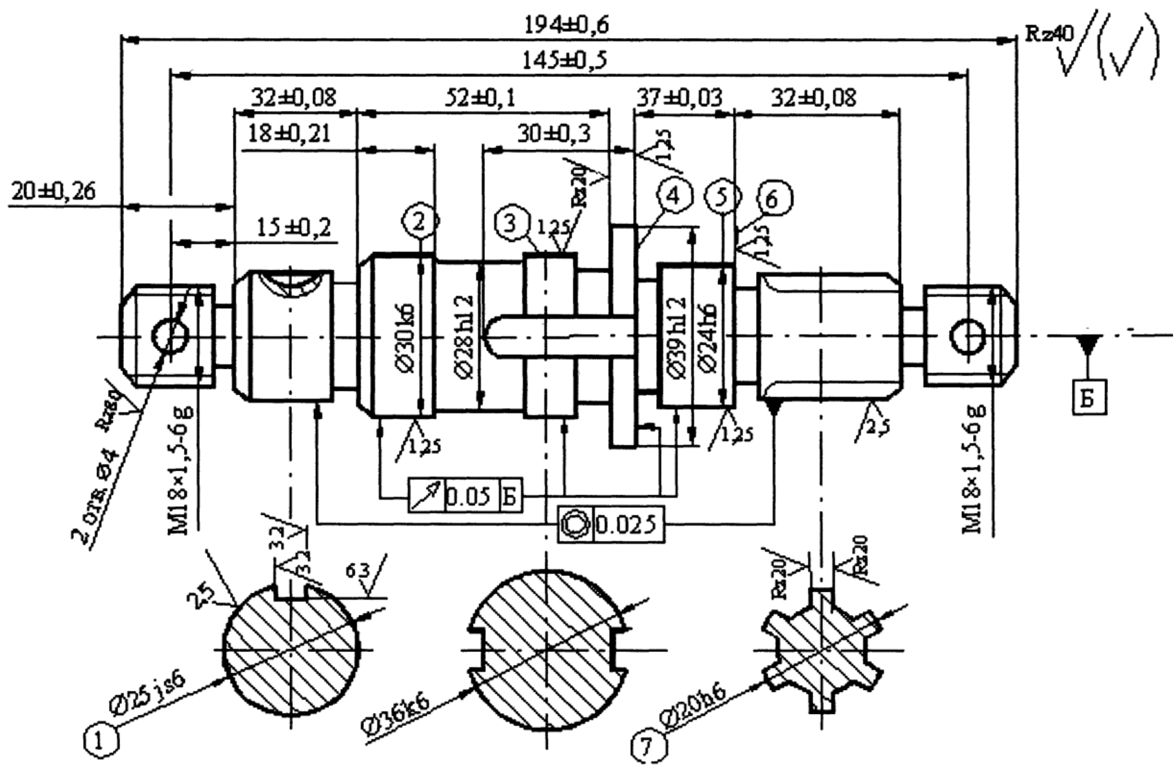


Fig. 27-7. Work drawing of the stepped shaft (example 2).

Operation 0 (blanking):

1. Forge the blank

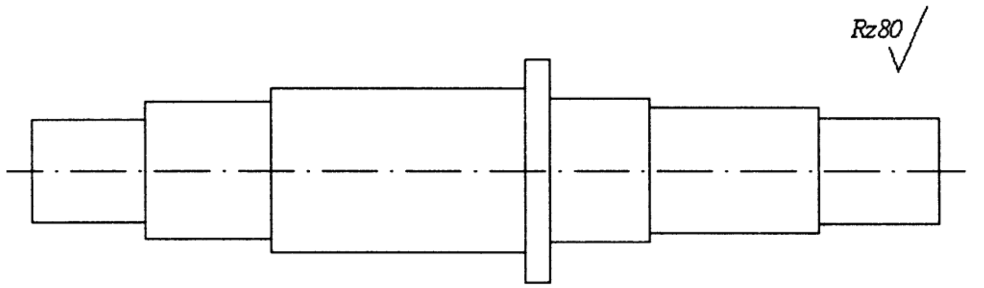


Fig. 27-8. Forged blank.

Operation 1 (milling- centering):

1) Mount a blank on prisms;
2) Mill ends 1 and 2 (sides A and B) of the shaft simultaneously;
3) Drill a center holes on ends 1and 2 simultaneously;
4) Take off the blank and put the processed detail in container.

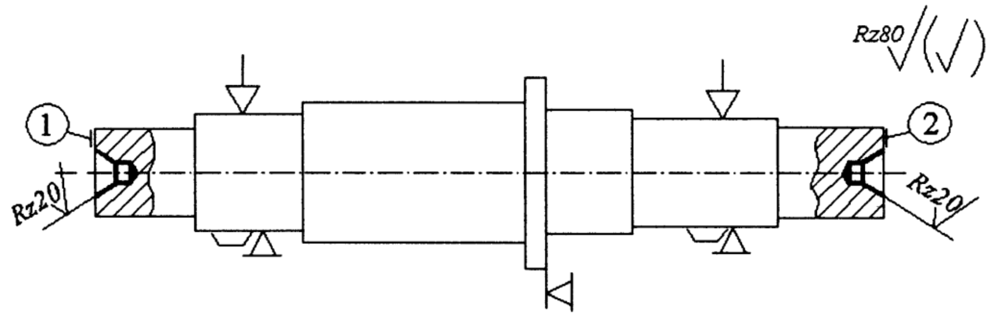
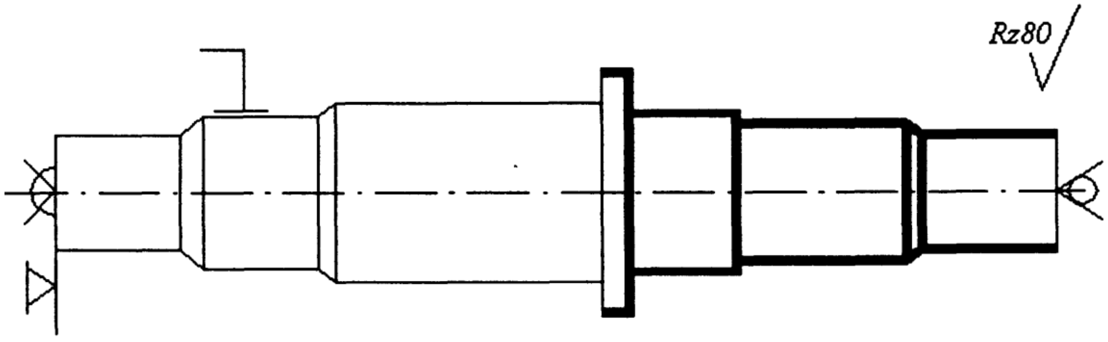


Fig. 27-9. Operation drawing of operation 1.

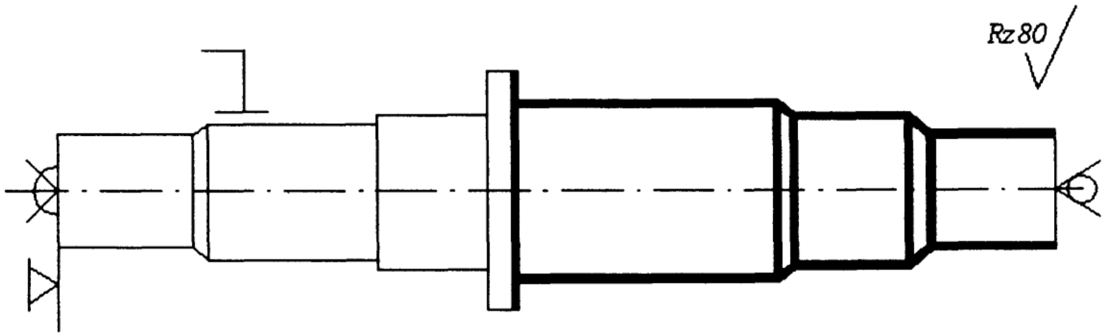
Operation 2 (copying-turning):
1) Fix a lathe dog;
2) Mount a blank between centers;
3) Turn off the shaft roughly on the side B;
4) Take off the blank and lathe dog,
put the processed detail in container



1. h11; ±IT11/2.

Fig. 27-10. Operation drawing of operation 2.

Operation 3 (copying-turning):
1) Fix a lathe dog;
2) Mount a blank between centers;
3) Turn off the shaft roughly on the side A;
4) Take off the blank and lathe dog,
put the processed detail in container

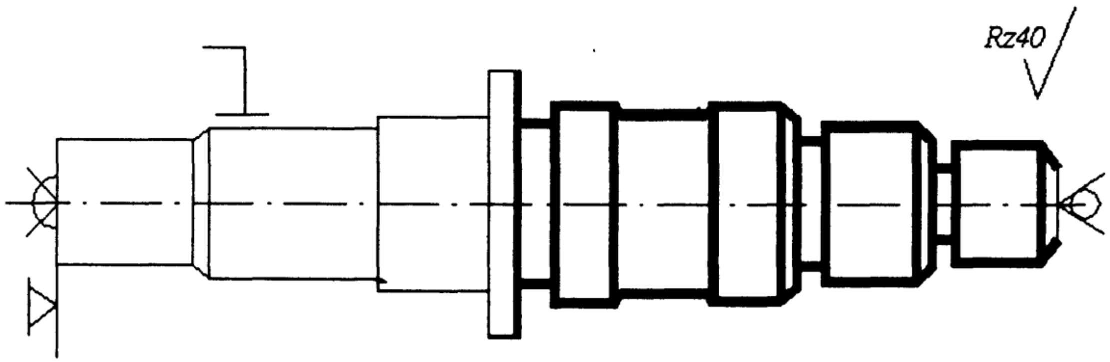


1. h11; ±IT14/2.

Fig. 27-11. Operation drawing of operation 3.

Operation 4 (copying-turning):

1) Fix a lathe dog;
2) Mount a blank between centers;
3) Turn off the shaft definitively on the side A;
4) Turn the surface 6;
5) Turn the surface 7;
6) Turn the surface 8;
7) Take off the blank and lathe dog,
   put the processed detail in container

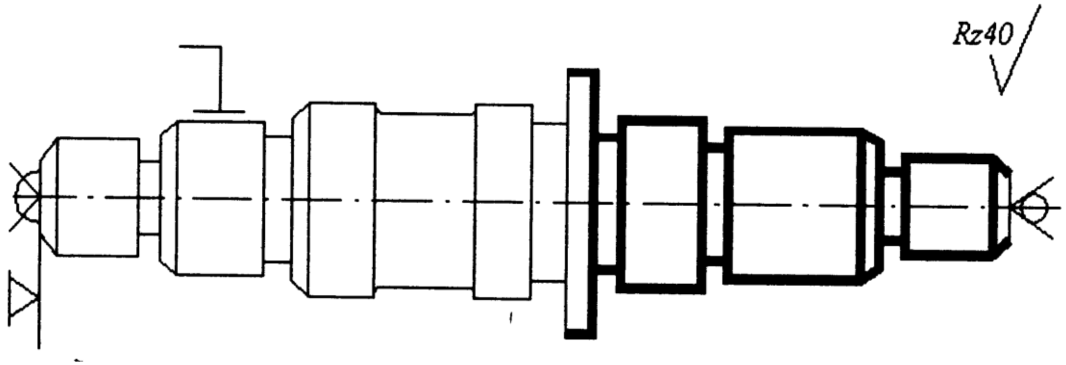


1. h9; ±IT14/2.

Fig. 27-12. Operation drawing of operation 4.

Operation 5 (copying-turning):

1) Fix a lathe dog;
2) Mount a blank between centers;
3) Turn off the shaft definitively on the side B;
4) Turn the surface 4;
5) Turn the surface 5;
6) Turn the surface 6;
7) Take off the blank and lathe dog,
   put the processed detail in container



1. h9; ±IT14/2.

Fig. 27-13. Operation drawing of operation 5.

Operation 6 (thread-turning):

Setting A

1) Fix a lathe dog;
2) Mount a blank between centers;
3) Turn the thread on the side A;

Setting B

4) Refix a lathe dog;
5) Mount a blank between centers;
6) Turn the thread on the side B;
7) Take off the blank and lathe dog,
   put the processed detail in container

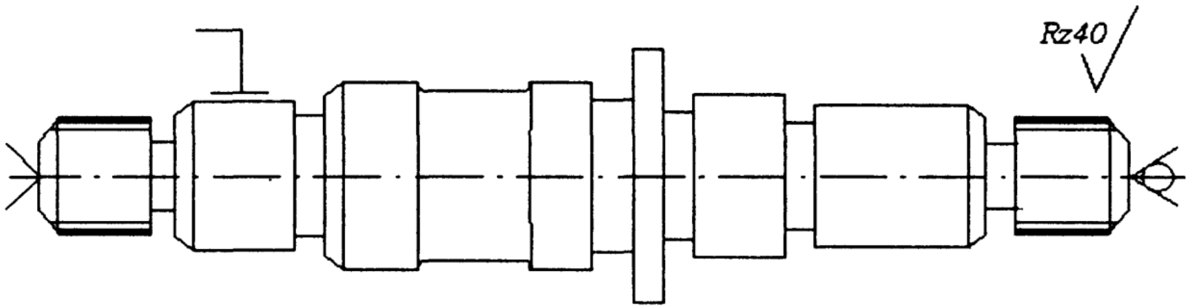


Fig. 27-14. Operation drawing of operation 6.

Operation 7 (milling):

Setting A

1) Mount a blank on prisms and fix it;
2) Mill slot on the upper side of the shaft;
3) Refix the shaft and return it;

Setting B

4) Mill slot on the bottom side;
6) Take off the blank and
   put the processed detail in container

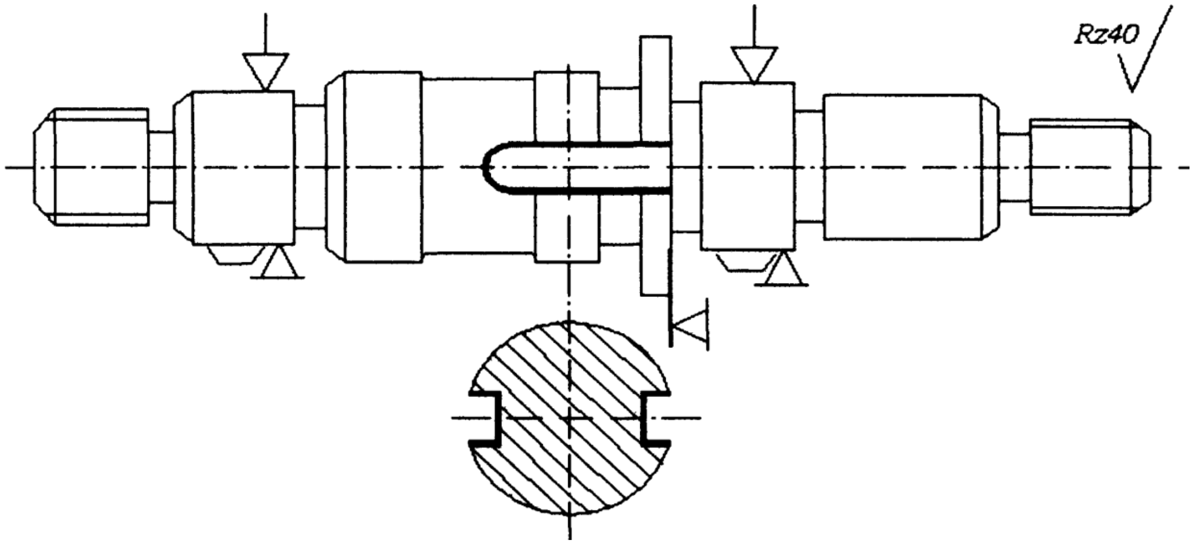


Fig. 27-15. Operation drawing of operation 7.

Operation 8 (milling):

1) Mount a blank on prisms and fix it;
2) Mill the slot;
3) Take off the blank and
   put the processed detail in container.

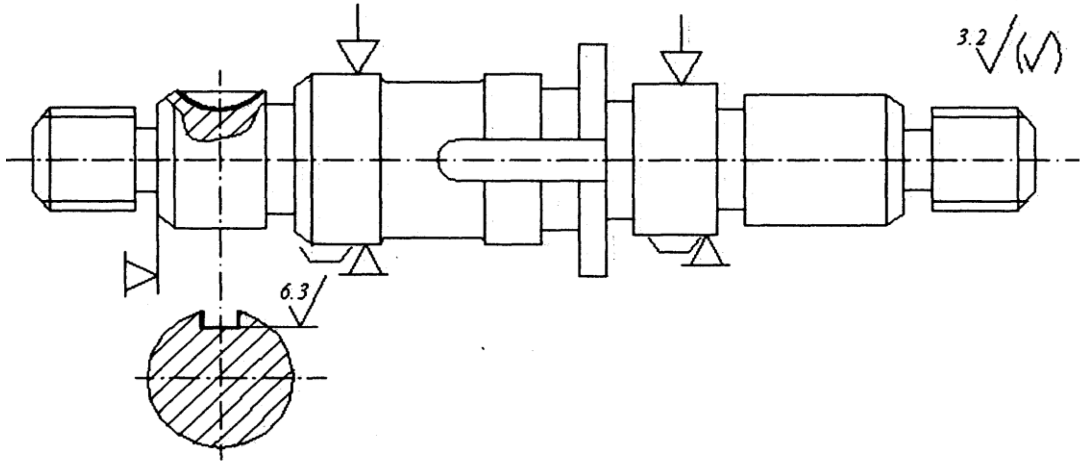


Fig. 27-16. Operation drawing of operation 8.

Operation 9 (milling):

1) Fix a lathe dog;
2) Mount a blank between centers;
2) Mill slots;
3) Take off the blank and
   put the processed detail in container.

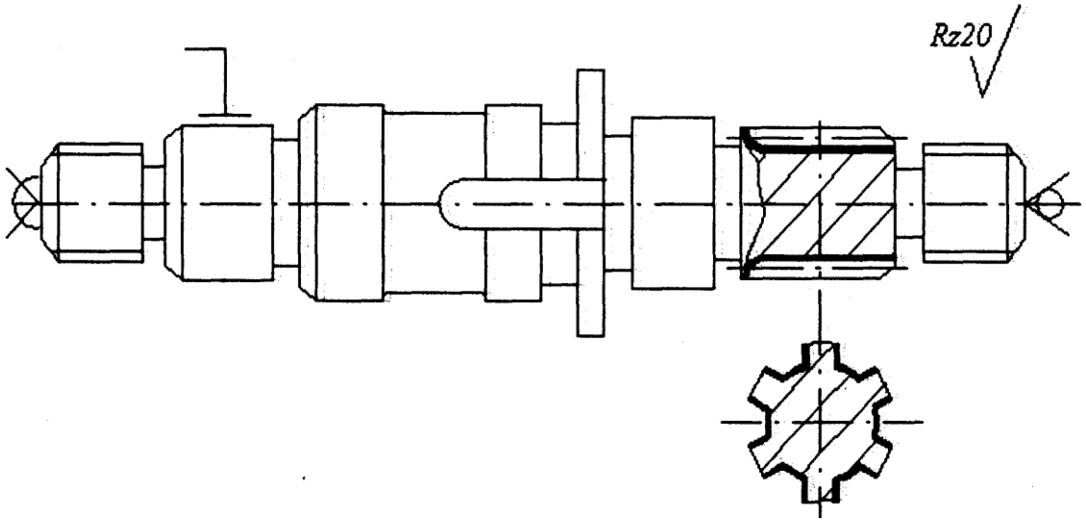


Fig. 27-17. Operation drawing of operation 9.

Operation 10 (drilling):

1) Mount a blank on prisms and fix it;
2) Drill the right hole;
3) Drill the left hole;
3) Take off the blank and
   put the processed detail in container.

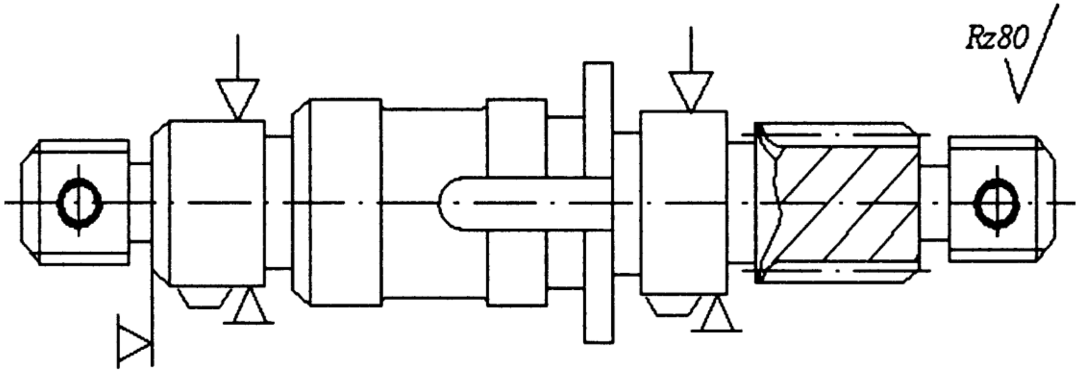


Fig. 27-18. Operation drawing of operation 10.

Operation 11 (metal worker's):

1) Filing sharp ends of the workpiece.

Operation 12 (controlling):

1) Check the workpiece.

Operation 13 (washing):

1) Wash the workpiece.

Operation 14 (heat treatmenting):

1) Harden the workpiece HRC_b 52…54.

Operation 15 (grinding):

Setting A

1) Fix a lathe dog;
2) Mount a blank between centers;
3) Grind surfaces 2 and 3 of side B;
4) Grind the surface 1 of side B;

Setting B

4) Refix a lathe dog;
5) Mount a blank between centers;
6) Grind the surface 5 of the side A;
7) Grind the surface 7 of the side A;
8) Take off the blank and lathe dog, put the processed detail in container

Operation 16 (controlling):

1) Check dimensions, roughness, positions of surfaces, hardness of the detail.

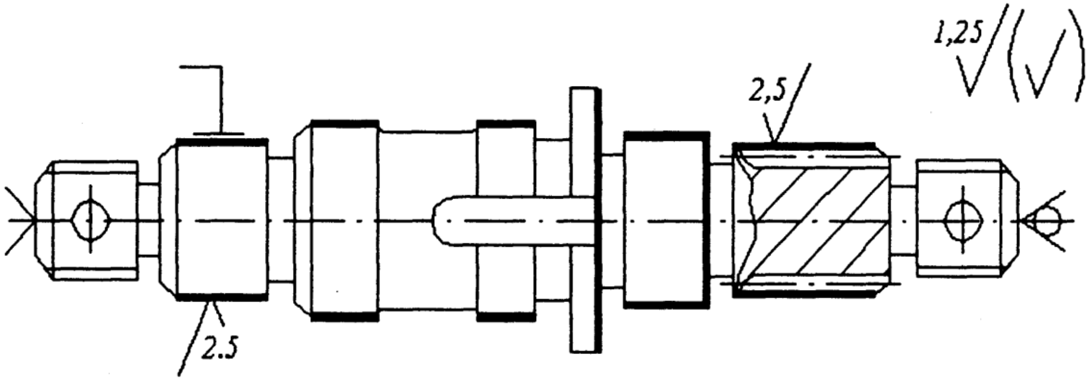


Fig. 27-19. Operation drawing of operation 15.

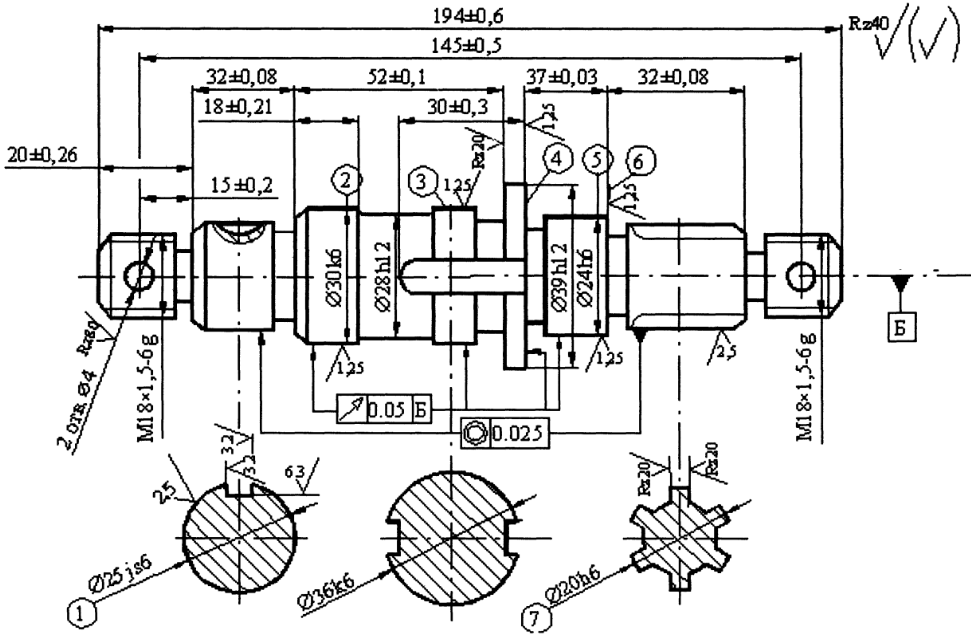
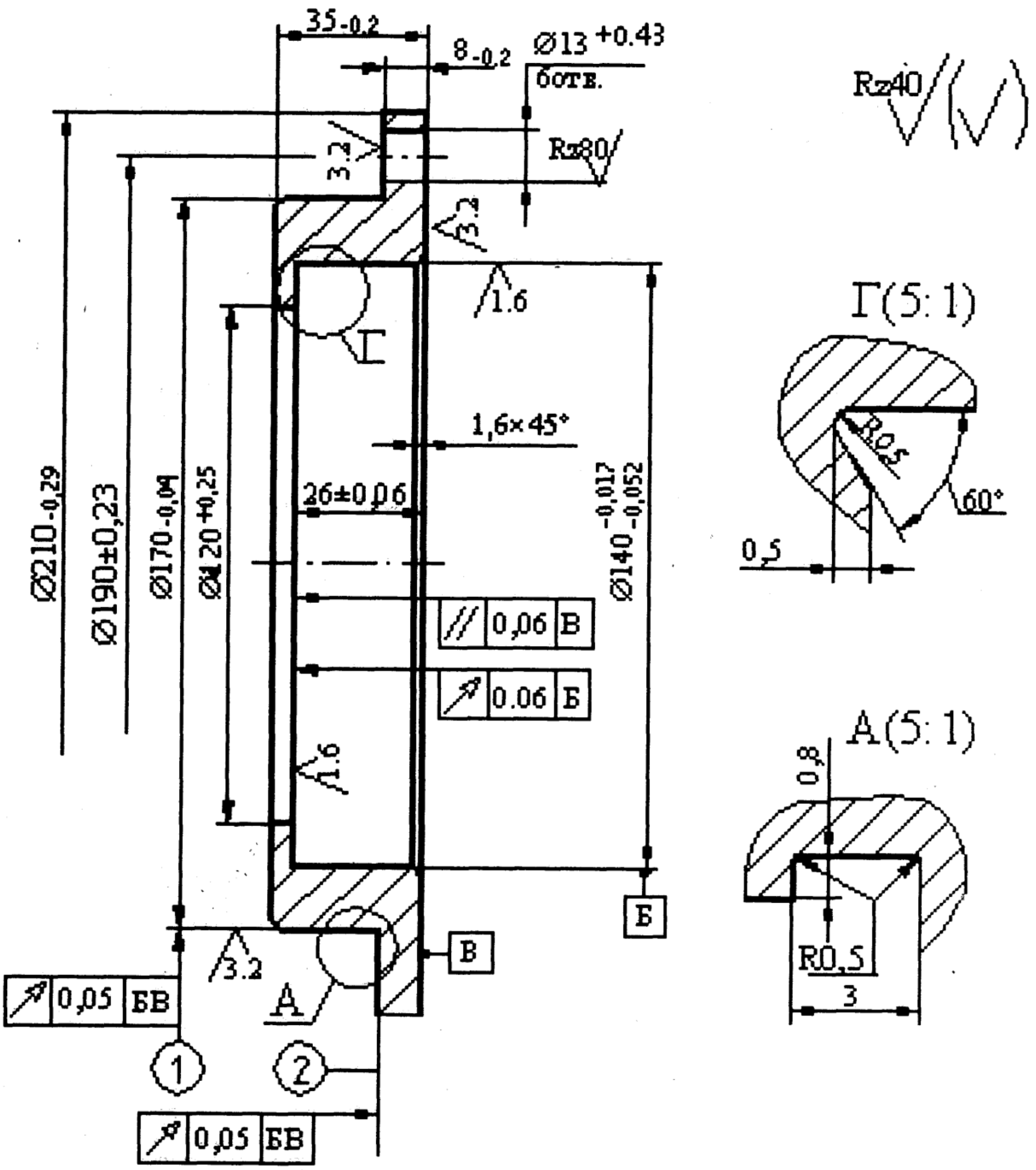


Fig. 27-20. Checking drawing of operation 16.

Example 3. Technological process of a disk (or a sleeve).

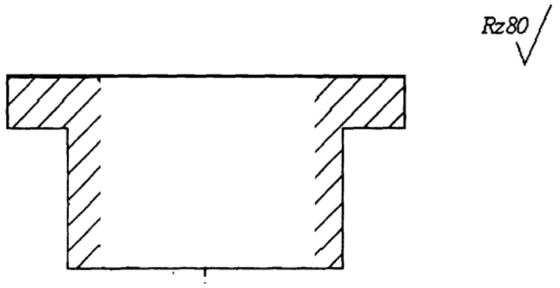


1. H14, h14, J_s14.
2. HB 220…260.
3. Cast iron 25.

Fig. 27-21. Working drawing of the disk.

Operation 0 (blanking):

1. Mold the disk blank.

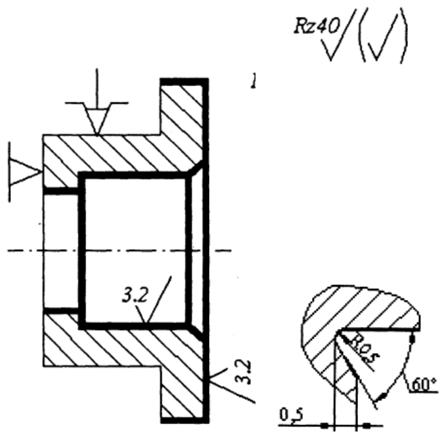


1.H14, h14.
2.HB 220…260.

Fig. 27-22. Operation drawings of the blank, operation 0.

Operation 1 (turning, 16K20):

1) Mount a blank in an universal 3-jaw chuck;
2) Turn off the right face end (1) of the blank (side A) L = 38h14($_{-0.62}$) mm;
3) Turn off the surface (2) ¢210h11($_{-0.29}$) mm;
4) Bore off the surface (3) ¢120H11($^{+0.25}$) mm;
5) Bore off the surface (4) ¢138H11($^{+0.25}$) mm roughly, machined surface (5) L = 14.2h14($_{-0.62}$) mm ;
6) Bore off the surface (4) ¢139.5H9($^{+0.1}$) mm semi finishly, machined surface (5) L = 14.2h14($_{-0.62}$) mm ;
7) Bore off the surface (6) L = 1.6h14($_{-0.62}$) mm ;
8) Bore off an overtravel *A* on the surfaces (4) and (5);
9) Take off the blank and put the processed workpiece in container.

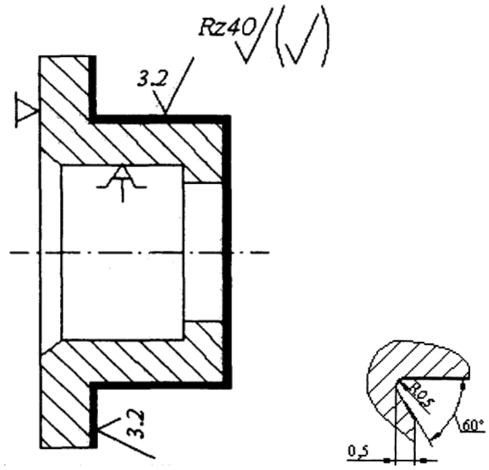


1. H11, h11.

Fig. 27-23. Operation drawings of operation 1.

Operation 2 (turning, 16K20):

1) Mount a blank on an selfcentering mandrel;
2) Turn off the face end (1) of the blank (side B) L = 35h12($_{-0.25}$) mm;
3) Turn off the surface (2) ¢172h11($_{-0.25}$) mm roughly, machined surface (3) L = 8.4h14($_{-0.36}$) mm ;
4) Turn off the surface (2) ¢170.5h9($_{-0.1}$) mm semi finishly, machined surface (3) L = 8.2h14($_{-0.36}$) mm ;

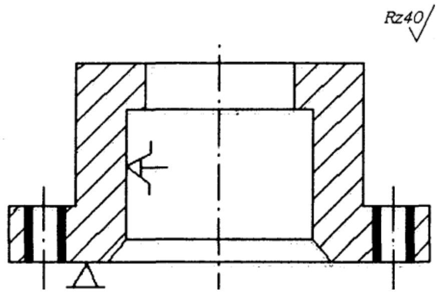


1. h11.

Fig. 27-23. Operation drawings of operation 2.

5) Turn off an overtravel *A* on the surfaces (2) and (3);
6) Take off the blank and put the processed workpiece in container.

Operation 3 (drilling, 2135):
1) Mount a blank on an selfcentering mandrel;
2) Drill 6 holes ¢13H14($^{+0.43}$) mm on ¢190J_s12(±0.23) mm simultaneously by using drill box and 6- spindle drilling head;
3) Take off the blank and put the processed workpiece in container.



1. H14.
Fig. 27-24. Operation drawings of operation 3.

Operation 4 (metal worker's):
1) Filing sharp ends of the workpiece.

Operation 5 (grinding, 3A151):
1) Mount a blank on an selfcentering mandrel;
2) Grind the surface (1) ¢170h7($_{-0.04}$) mm definitively, machined surface (2) L = 8h13($_{-0.22}$) mm ;
4) Take off the blank and put the processed workpiece in container.

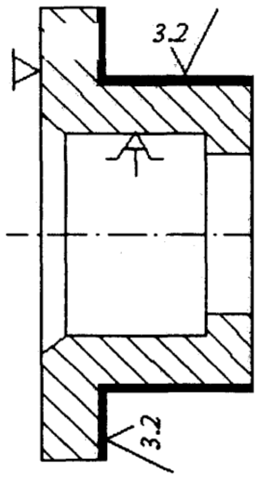


Fig. 27-25. Operation drawings of operation 5.

Operation 6 (grinding, 3A251):
1) Mount a blank in an collet chuck;
2) Grind the surface (1) ¢140N7($_{-0.052}^{-0.017}$) mm definitively, machined surface (2) L = 26J_s11(±0.06) mm ;
3) Take off the blank and put the processed workpiece in container.

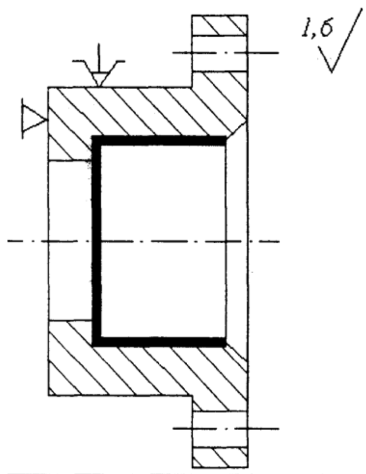


Fig. 27-26. Operation drawings of operation 6.

Operation 7 (metal worker's):
1) Filing sharp ends of the workpiece.

Operation 8 (washing):
1) Wash the detail.

Operation 9 (controlling):
1) Check the detail.

Chapter 28. Design of Parts to Be Machined

Machining is one of the most laborious and expensive methods of manufacture and amounts to 70 per cent of the cost of a product.

The principal production methods of increasing the machining efficiency are as follows.

1. Reduction of **machining time** (intensification of cutting processes). These methods include **high-speed cutting** (increasing the main cutting speed), **heavy-duty cutting** (increasing the cutting feed and depth), and **high-productivity processing** (machining with multipoint tools; internal and external broaching; turn-milling; etc.).
2. Reduction of **handling time** (the use of quick-acting attachments; automatic feed, mounting, fastening and removal of the blank; machining to preset operations; automatic readjustment of the machine set-up; and automatic control). Another form of this method is the consecutive machining of blanks in multistation fixtures.
3. Matching of process operations in time (proper sequencing of operation elements). This method includes machining with combination tools and multiple-tool machining (multi-cutter turning and planing; milling with a set of milling cutters). The method is most fully embodied in unit-head machine tools in which several surfaces of a blank are machined simultaneously.
4. Simultaneous machining of several blanks (parallel and parallel-consecutive machining in multi-station fixtures; continuous machining on rotary and drum-type machine tools and on vertical turret lathes).
5. Rapid transfer of blanks from machine to machine (mechanical transportation of blanks; rational arrangement of equipment). Automatic and semi-automatic transfer lines, especially those of rotary type, are most productive.

Mass and stable production and all-round unification of designs with few models are requisite for the application of highly productive machining methods, special manufacturing riggings and special-purpose machine tools.

When designing parts to be machined the labour required by the machining process should be reduced to the minimum, and high quality, reliability and durability of machines ensured at the same time.

When designing parts for machining the following rules are to be observed:

1. reduce the length of work surfaces to the design minimum required;
2. decrease the machining allowances to the minimum;
3. manufacture parts by the most productive methods which do not involve chipping (forging, cold upsetting, coining, etc.);
4. widely use shape steel rolled stock, leaving most of the surfaces in the as-rolled condition;
5. make parts from blanks having their shape as close as possible to that of the final product;

6. use composite structures to make easier the manufacture of labour-consuming parts;
7. avoid unnecessary precise machining. In each particular case use the lowest grade of accuracy ensuring proper functioning of the unit and meeting interchangeability requirements;
8. provide for the use of the most effective machining methods (with calibrated multipoint tools, etc.);
9. provide as far as possible for through-pass machining, which is the principal condition for increasing productivity and obtaining high-accuracy and finish standards of the machined surfaces;
10. if through-pass machining proves impossible, ensure that the tool overtravel is sufficient to obtain well-finished and accurate surfaces;
11. ensure convenient approach of the cutting tool to the work surfaces;
12. make it possible to machine the maximum number of surfaces during one operation on one machine in a single setting and with one and the same tool;
13. shape parts of repeated and mass application so as to make them suitable for group machining with the use of combination tools;
14. provide for the machining of accurate coaxial and parallel holes in a single setting to obtain good alignment and precise centre distances;
15. assure a clear distinction between the surfaces machined in different operations, by different tools and to different accuracies;
16. provide for the distances between the work and nearest rough surfaces which will make machining possible with the maximum variations in the blank size;
17. avoid joint machining of assembled parts, which disturbs the continuity of the production process, impairs interchangeability and makes it difficult to replace parts during operation;
18. reduce the range of the tools employed by unifying the size and shape of the elements to be machined;
19. in piece and small-lot production reduce the number of special cutting tools to a minimum, using standard tools as far as possible;
20. impart to the work surfaces such a shape as will make the tool operate smoothly without impacts;
21. relieve cylindrical multipoint tools (drills, reamers, counterbores, etc.) from a unilateral pressure in operation;
22. impart to the portions to be machined a high and uniform rigidity ensuring an accurate machining to good finish and making for the use of efficient processing methods;
23. provide convenient datum surfaces for size control with the use as far as possible of universal measuring tools.

28.1. Cutting Down the Amount of Machining

The examples in Fig. 28-1 show how superfluous machining can be eliminated. In the fastening unit of a guideway (Fig. 28-1*a*) it is advisable to reduce the depth of the locating slot in the housing (Fig. 28-1*b*) to an amount sufficient for reliable locking.

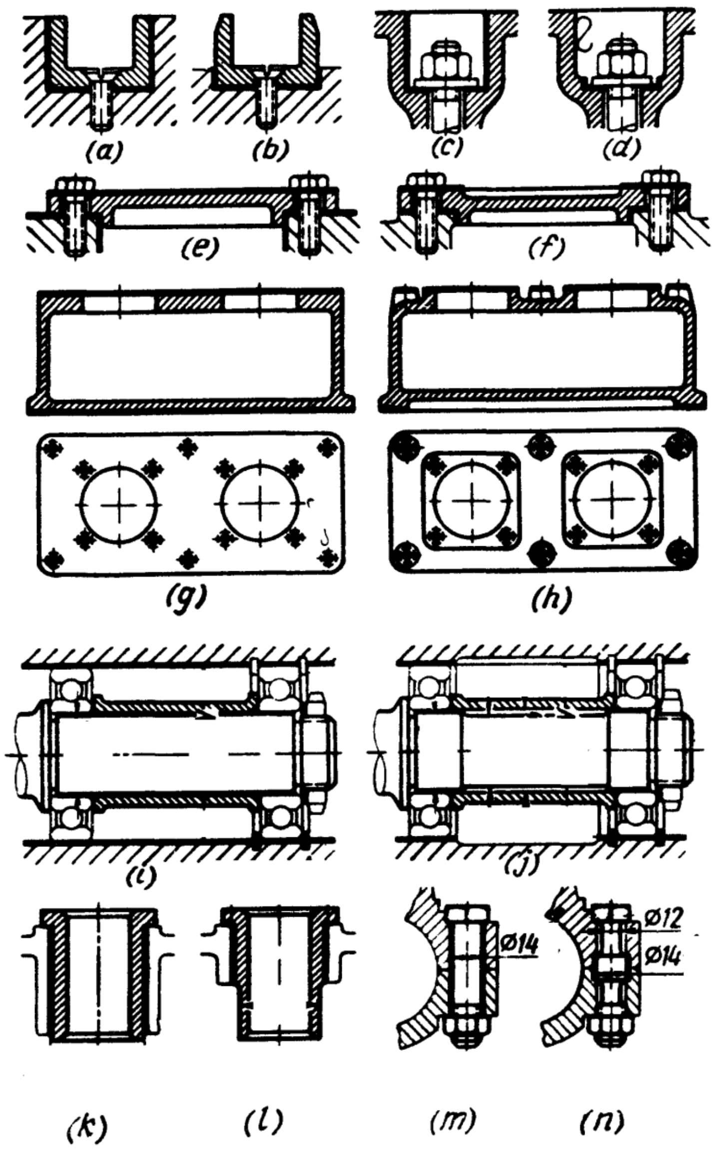


Fig. 28-1. Cutting down the amount of machining.

In cast parts (pit for a fastening bolt, Fig. 28-1*c* and *d*;cover, Fig. 28-1*e* and *f*; housing, Fig. 28-1*g* and *h)* the surfaces to be machined should be arranged above the adjacent rough surfaces.

In an antifriction bearing unit (Fig. 28-1*i*) precision machining should be applied to strictly limited portions of the working surfaces (Fig. 28-1*j*).

Figure 28-1*k* and *l* shows the shortening of the press-fitted portion of a bushing in a housing, and Fig. 28-1*m* and *n*, the reduction of the centering portion of a dowel bolt.

For parts made of round rolled stock the labour required for machining and the amount of chips removed can be reduced mainly by decreasing the difference between the diameters of the parts, especially the largest diameters which determine in the first place the amount of the cut-off material.

The shoulder on a stepped shaft (Fig. 28-2*a*) increases the diameter D of the blank and sharply increases the amount of the cut-off metal. The large difference between the step diameters requires in turn more machining. The volume of the cut-off metal amounts to 135 per cent of that of the final product. The coefficient of utilization of the material of the blank is 0.43, i.e., more than half of the blank metal is rejected as chips.

In the shaft design without shoulder and with a smaller difference in the step diameters (Fig. 28-2*b*) three times less metal is removed as compared with the previous case, thanks to the smaller diameter *D*. Most of this reduction to diameter D_1 (80 per cent) is due to the elimination of the shoulder. The coefficient of utilization of the material is increased to 0.7.

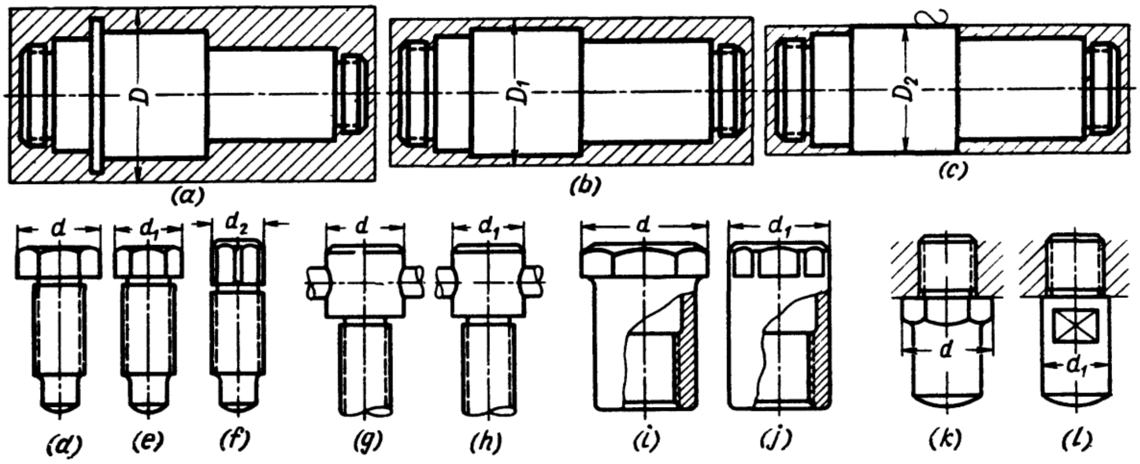


Fig. 28-2. Parts made of round rolled stock.

Fig. 28-2*c* illustrates a further reduction in the amount of the metal removed, made on account of the part being manufactured from a cold-drawn bar with a diameter equal to the maximum diameter D_2 of the shaft. In this case the coefficient of utilization of the material is increased to 0.8.

Examples of cutting down the amount of machining by reducing the maximum diameter of parts are illustrated in Fig. 28-2*d-f* (pressure screw), Fig. 28-2g, *h* (tommy bar head), Fig. 28-2*i,j* (cap) and Fig. 28-2*k,l* (leg).

The diameter of a product should corresponl to the standard diameters of round rolled stock. The maximum diameter ol a product should be less than the nearest standard diameter of the bar by an amount equal to the diametric machining allowance.

28.2. Press Forging and Forming

It is most advisable to make parts from blanks having their shape close to that of the final product, obtained by hot forging in closed-impression dies. This reduces the amount of machining and increases the strength of the part, thanks to the compaction of the metal, formation of fibre structure and fine equal axial grains resulting from recrystallization which occurs as the blank cools down.

All other conditions being equal, forgings are stronger and lighter, and require less machining than composite parts.

The use of dies is economically justifiable in mass production where the initial investments in. the manufacture of dies are rapidly recouped because of increased output and reduced machining. However, thanks to the high strength of forged parts, the method is often used in the manufacture of important machines irrespective of the scale of output and manufacturing costs.

The highest accuracy and surface finish standards are provided by cold sizing (coining) applied as a final operation after hot forging. In some cases coining completely dispenses with machining.

Fig. 28-3 illustrates methods of making a cup-shaped part (shown on the drawing by thin lines).

Much labour is required to turn the part out of a cylindrical blank (Fig. 28-3a). Besides, the part is weakened because the metal fibres are cut.

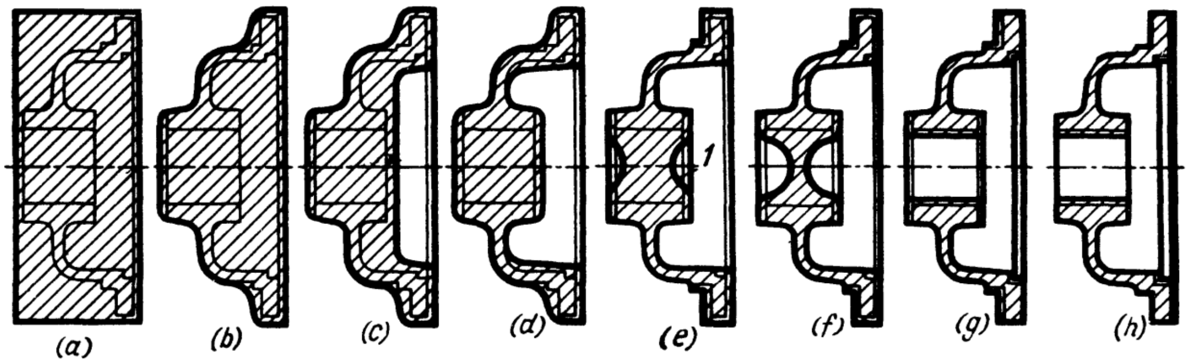


Fig. 28-3. Methods of making a cup-shaped part.

Fig. 28-3*b* shows a blank obtained by hammer forging in open dies with a profiled lower die and flat upper die; Fig. 28-3*c* and *d* illustrates the same blank made with the use of profiled lower and upper dies.

When the blank is forged in a closed single-impression die (Fig. 28-3*e*) most of the surfaces take the final shape except for the surfaces to be machined. The hole is marked by recesses *1.* The flash in the hole is removed by machining or subsequent forging operations.

Forging in a finish impression (Fig. 28-3*f*) provides a higher wall accuracy and in this case smaller machining allowances can be assigned. The partition in the hole is cut out by a punching die.

A blank with pierced hole obtained on a horizontal forging machine is presented in Fig. 28-3*g*.

Cold sizing (coining) imparts the final shape to all surfaces (Fig. 28-3*h*) except for the surfaces which require a most precise machining (seating hole, centering recess, end face of flange).

Flat shaped parts are advisably made of plate material with gang form milling or shaping of the external contour. The required section can also be obtained by extrusion. The parts in this case are produced by cutting the extruded section to the required length.

28.3. Through-Pass Machining

The through-pass machining where the cutting tool freely approaches and leaves the work surface is of great value for raising productivity and improving surface finish and accuracy.

The housing design in Fig. 28-4*a* is not good since the traverse of the cutting tool (face milling cutter) along the work surface is limited by the housing walls.

The cutting conditions vary with different portions of the surface. At first the blank is brought to the cutter axially, then the cutter bites into the metal, in which case it is difficult to obtain fine surface. Several cuts are required to obtain more or less identical finish over the entire length of the machined surface.

Such productive methods as high-speed cutting, machining to preset operations and also gang machining cannot be applied in this case. Each workpiece has to be machined individually, much time being wasted to feed the milling cutter in and back it out, and adjust the setup to size.

In the correct design with the protruding work surface (Fig. 28-4*b*) the milling cutter operates with through feed and cuts the surface to the same finish at a high productivity.

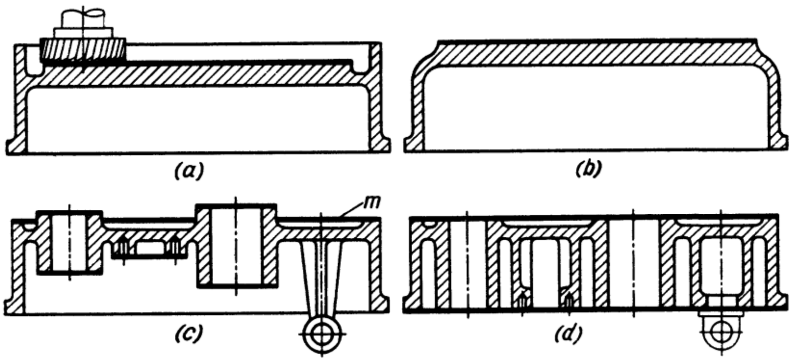


Fig. 28-4. Through-pass machining of frames.

Fig. 28-4*c* shows a plate design unsuitable for mass production. The work surfaces are arranged at different levels, each surface requiring individual machining. Due to the presence of internal bosses, the contour of the upper flange *m* has to be machined with a combined cross and longitudinal feed of the work. The bracket with a transverse hole, which protrudes below the lower surface of the plate, makes it difficult to machine this surface and mount the plate properly when machining the upper surfaces. It is inconvenient to drill the transverse hole in the bracket, especially if the hole is far from the external edges of the plate.

In the good design (Fig. 28-4*d*) all the work surfaces are brought to the same level. The bracket is made detachable. The machining is done in two stages: first the upper surface is cut and then the lower one.

Fig. 28-5 shows examples of machining accurate holes. In design *1* the bearing is installed in a split housing (radial assembly), in a recess limited on both sides by walls. It is extremely difficult to machine the seating surface of the recess.

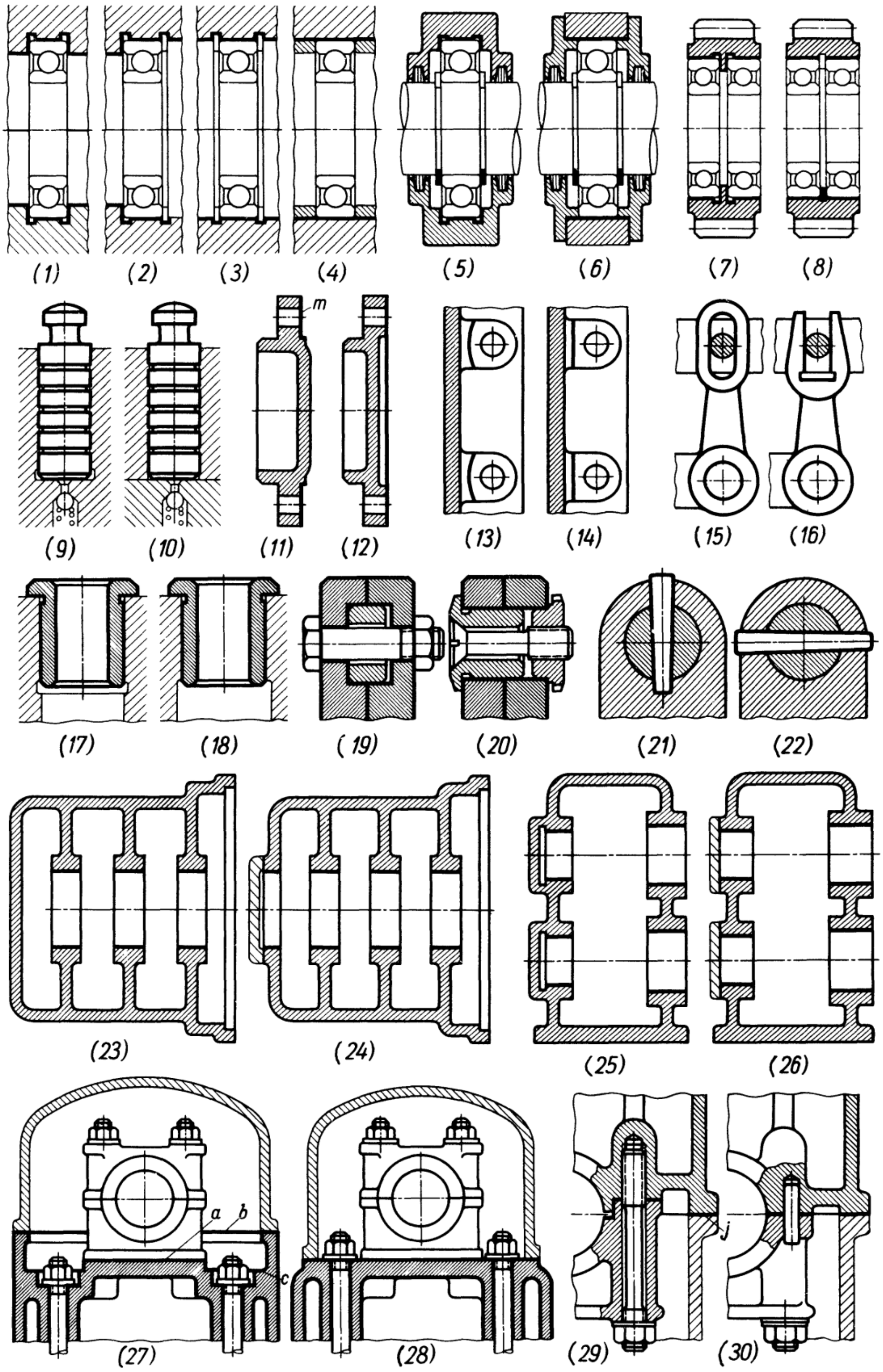


Fig. 28-5. Through-pass machining of holes.

If the seats for the gears are blind and are arranged in different halves of the housing that design is unsuitable for mass production. In such conditions it is difficult to coaxially align the seats. A better design is the one where the seats are situated in one half of the housing. The best design is the one where the housing is composed of three parts. The seats in the middle portion of the housing and the working surfaces of the housing cheeks are through-pass machined.

28.4. Overtravel of Cutting Tools

Sometimes through-pass machining is impossible for design considerations. In such cases provision should be made for an **overtravel** of the cutting tool with respect to the work surface to a distance sufficient to obtain the specified finish and accuracy. When machining accurate stepped cylindrical surfaces the over-travel of the tool is ensured by means of grooves several tenths of a millimeter deep cut at the section transitions.The dimensions of the grooves (in mm), depending on the diameter d_0 of the cylinder, are given below.

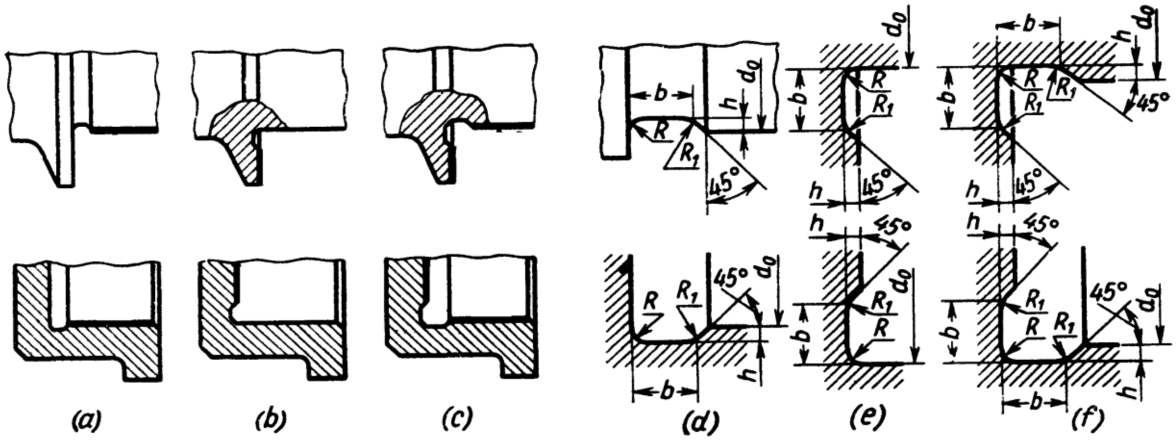


Fig. 28-6. Grooves for the overtravel of cutting tools.

Table 28-1. The dimensions of the grooves (mm), depending on the diameter d_0 of the cylinder

Nomenclatures of groove	The diameter d_0 of the cylinder, mm			
	up to 10	**10 – 50**	**50 – 100**	**over 100**
b	2	3	5	8
h	0.25	0.25	0.5	0.5
R	0.5	1.0	1.5	2.0
R_1	—	≈ 2 h	—	—

If a cylindrical surface alone is subject to precision machining, use is made of cylindrical recesses (Fig. 28-6*a*), and when end faces are to be accurately machined (Fig. 28-6*b*) end recesses are cut. Diagonal grooves are made when a cylinder and the adjoining end face are to be precision machined (Fig. 28-6*c*). The shapes of grooves for the overtravel of a grinding wheel are illustrated in Fig. 28-6*d* (cylindrical grinding), *e* (face grinding) and *f* (cylindrical and face grinding).

Fig. 28-7 presents the shapes of adjoining surfaces of standard parts used in mechanical engineering.

It is impossible to finish machine the portion of a stepped shaft (Fig. 28-7, *1*)

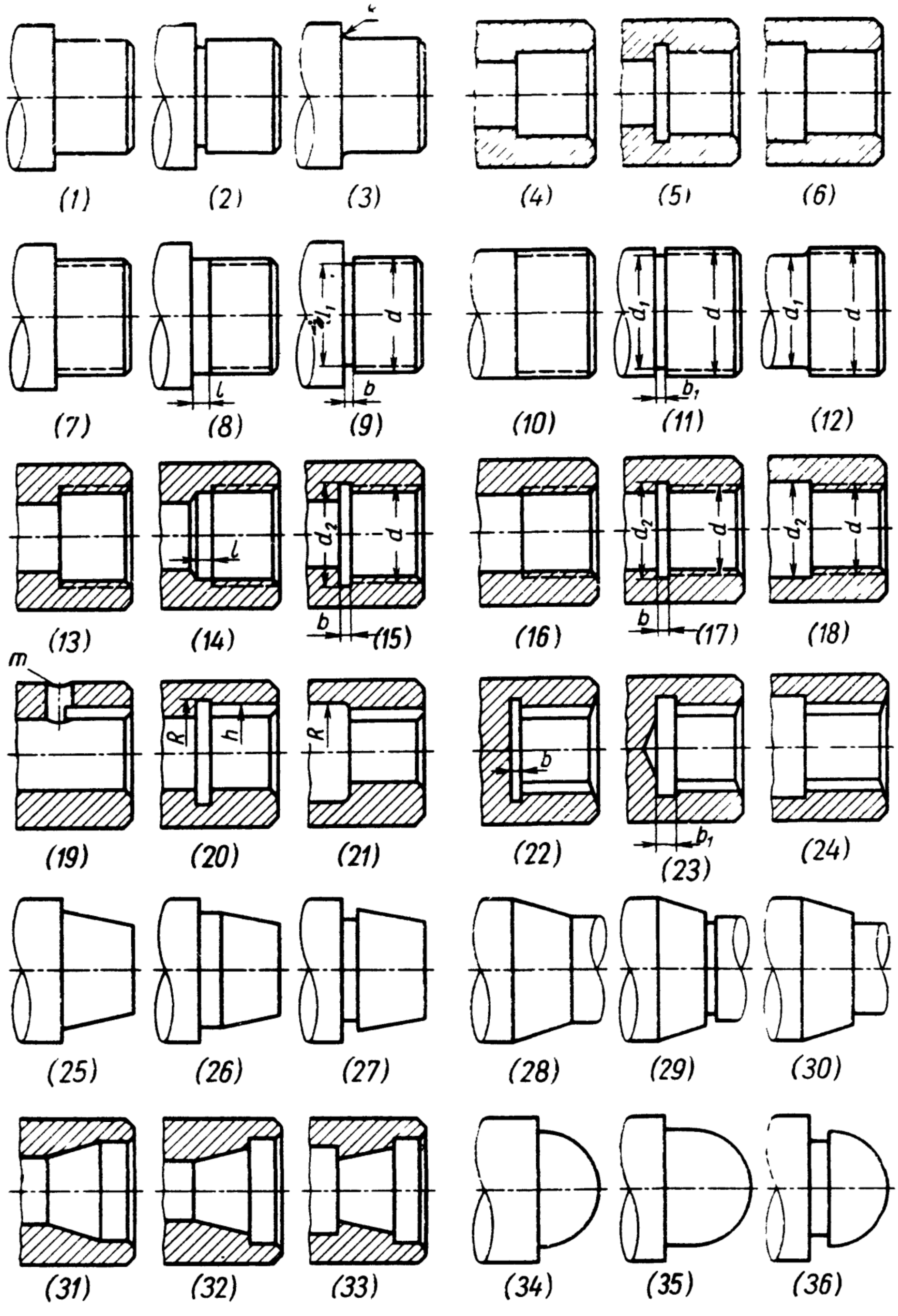


Fig. 28-7. Adjoining surfaces.

where the cylindrical surface adjoins the end face of the collar. To ensure tool overtravel, a groove should be provided at the point of transition (Fig. 28-7, *2*). This method is not recommended for heavily loaded parts because recesses act as stress concentrators. In such cases a filleted transition (Fig. 28-7, *3*) is required, made with a round-nose tool in turning, and with a round-face wheel in grinding.

To obtain accurate inner surfaces (Fig. 28-7, *4*), it is necessary to introduce undercut grooves (Fig. 28-7, *5*) or, better still, to ensure through-pass machining (Fig. 28-7, *6*).

Designs in which threads on cylindrical stepped portions are cut close to the end faces of the steps (Fig. 28-7, *7, 13*) are practically impossible. Threads should terminate at a distance $l > 4S$ from shoulders or end faces (Fig. 28-7, *8, 14)*, where S is the thread pitch, or separated from the adjacent surfaces by a groove (Fig. 28-7, *9, 15)* with a diameter $d_l \leq d - 1.55\ S$ for external threads and $d_2 \geq d + 0.25$ for internal threads, where d is the nominal thread diameter in mm.

When cutting external threads with threading tools or dies the width of the grooves is, on the average, $b = 2S$, and when cutting internal threads, $b = 3S$. It is advisable to observe this rule also in the case of smooth shafts (Fig. 28-7, *10, 11*) and holes (Fig. 28-7, *16*, *17*).

Surfaces adjacent to threads should preferably be arranged lower (Fig. 28-7, *12, 18*) to allow through-pass machining. The diameters d_l and d_2 of such surfaces are determined from the relations given above.

When cutting longitudinal slots in holes, provision should be made for the slotting tool exit, for example, into a transverse bore *m* (Fig. 28-7, *19*) or into an annular groove (Fig. 28-7, *20*) of radius $R \geq (h^2 + c^2/4)^{0.5}$ (where h is the distance from the slot bottom to the centre and c, the slot width). It is better for the adjacent surface to be located below the slot bottom (Fig. 28-7, *21*).

The design of a blind hole with splines machined by broaching (Fig. 28-7, *22)* is wrong: the width b of the groove beyond the splines is not enough for the overtravel of the broaching tool. In the design shown in Fig. 28-7, *23* the length of the splines is reduced and the groove is made of greater width b'. The lowering of the adjacent surface (Fig. 28-7, *24*) enables one to broach the splines more effectively and accurately.

Fig. 28-7, *25, 28, 31* shows unsuitable shapes of tapering surfaces which do not allow overtravel and infeed of the tool. Correct designs are illustrated in Fig. 28-7, *26, 27, 29, 30, 32, 33*. Figure 28-7, *34, 35* shows irrational and Fig. 28-7, *36*, rational designs of spherical surfaces.

Let us discuss examples of wrong and correct designs of standard units and parts used in mechanical engineering.

In the design of a splined shaft with straight-sided splines (Fig. 28-8, *1)* it is impossible to grind the working faces and the centring surfaces of the shaft. To permit overtravel of the grinding wheel the surface of the shaft should be lowered at the base of the splines (Fig. 28-8, *2*), or grooves should be made (Fig. 28-8, *3*).

Figure 28-8, *4, 5* shows wrong and correct designs of an inverted V-guideway, respectively, and Fig. 28-8, *6*, *7*, those of a snap limit gauge.

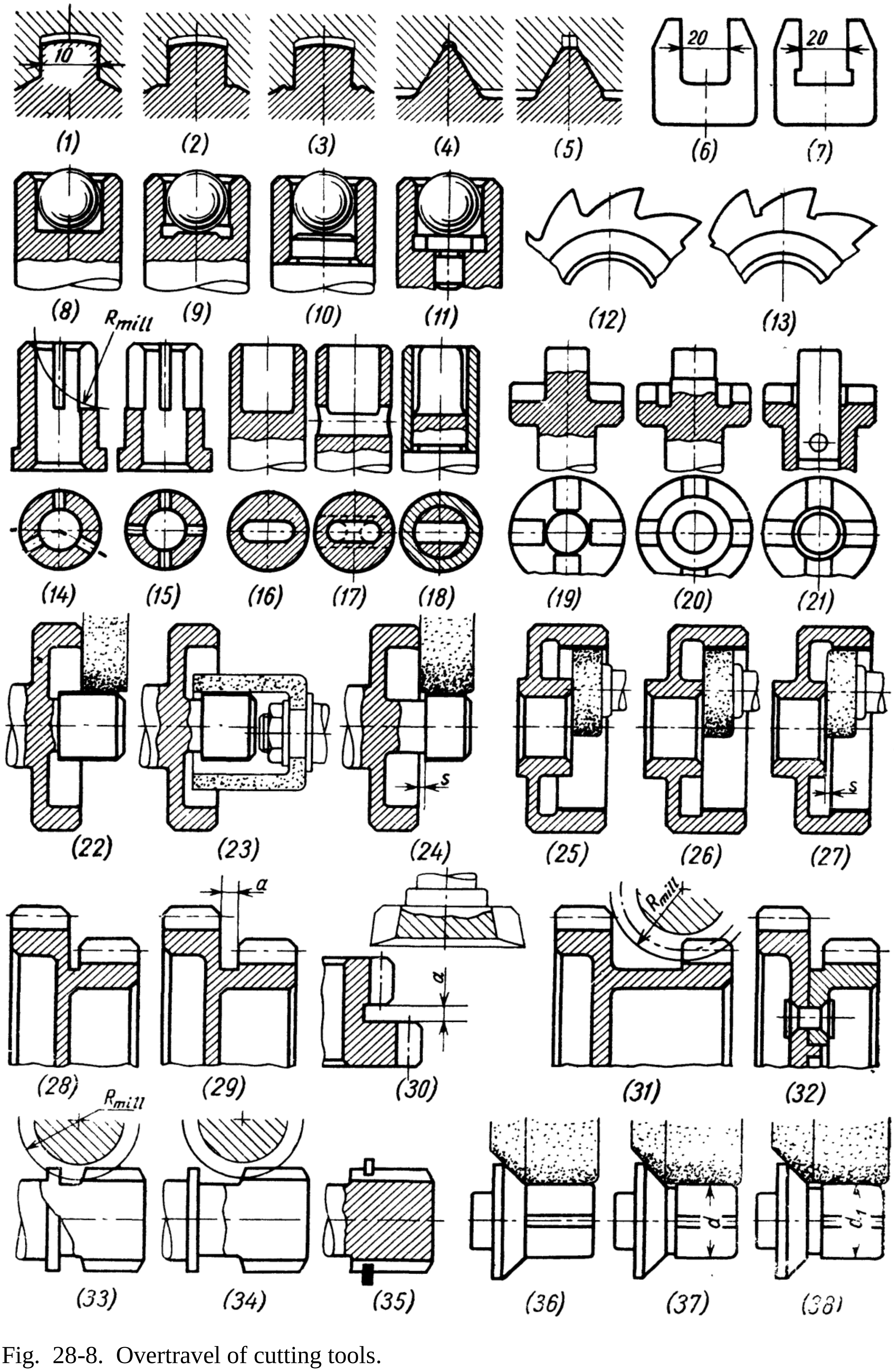


Fig. 28-8. Overtravel of cutting tools.

The internal space of a step ball bearing (Fig. 28-8, *8*) can be machined easier if a groove is made at the base of the space (Fig. 28-8, *9*) or if use is made of composite structures (Fig. 28-8, *10, 11*).

In the free wheel (Fig. 28-8, *12*) the spiral active surfaces of teeth (usually worked on relieving grinding machines) should be provided with undercuts to allow for overtravel of the grinding wheel (Fig. 28-8, *13*).

It is impossible to mill the slots in the slotted bushing (Fig. 28-8, *14*) because the cutter comes against the bushing wall. If four instead of three slots are used (Fig. 28-8, *15*) they can be through-pass milled.

It is very difficult to machine the end slot in the shaft (Fig. 28-8, *16*). If the cutting tool overtravel is permitted into a transverse bore at the base of the slot (Fig. 28-8, *17*), the shaft end then can be drilled at the slot edges (dashed lines) and the partition between the drilled holes removed by planing. A composite design comprising a rim press-fitted onto the slotted portion of the shaft requires still simpler machining (Fig. 139, *18*).

End slots on a shaft (Fig. 28-8,*19*) can only be formed by upsetting. Separating the slots from the cylindrical surface of the shaft by an annular groove (Fig. 28-8, *20*) enables one to make them by planing. In the composite design (Fig. 28-8, *21*) the slots can be machined more accurately and efficiently by through-pass milling.

In the cup-shaped part (Fig. 28-8, *22*) the neck of the shaft can be ground only by a very expensive and inefficient method using a cup wheel mounted eccentrically with respect to the shaft (Fig. 28-8, *23*). To make cylindrical grinding possible the shaft journal should protrude beyond the cup to a distance *s* sufficient for overtravel of the wheel (Fig. 28-8, *24*).

In another cup-shaped part (Fig. 28-8, *25*), the grinding of the internal surface is hindered by the projecting end of the hub. The design in Fig. 28-8, *26* is also wrong because the end of the surface being ground coincides with the end of the hub, and a burr appears on the extreme portions of the surface.

In the correct design shown in Fig. 28-8, *27* the end of the hub is displaced relative to the surface being ground to a distance *s* thus ensuring a good finish of the entire surface.

In the cluster gear (Fig. 28-8, *28*) the teeth of the pinion can be cut if the distance a (Fig. 28-8, *29*) is made sufficient for overtravel of the gear cutter (Fig. 28-8, *30*). The minimum value of *a* (mm) as against the tooth module *m* is given below.

m	1-2	3-4	5-7	8-10	12-14
a	4-5	6-7	8-9	10	14

When teeth are formed by a hob cutter much larger distances are required, determined by the diameter of the cutter (Fig. 28-8, *31*) and the plan approach angle with respect to the shaft axis. If the rims have to be close together, composite designs are used (Fig. 28-8, *32*).

To prevent the hob cutter from cutting into the thrust shoulder of the shaft (Fig. 28-8, *33*) when the splines are machined by the generating method, the shoulder must be positioned at such a distance from the shaft end as will permit the machining of the splines without the tool cutting into the shoulder (Fig. 28-8, *34*). The best way is to through-pass machine the splines and replace the shoulder with a circular stop (Fig. 28-8, *35*).

Fig. 28-8, *36* shows a conical valve with a guiding shank. The valve chamfer and the centering surfaces of the shank are plunge-cut ground with a form wheel. In this design it is impossible to finish grind the portion where the chamfer adjoins the shank. The design with a recess (Fig. 28-8, *37*) is also wrong because the diameter *d* of the shank is equal to the smaller diameter of the chamfer and a burr may appear on the chamfer. In the correct design shown in Fig. 28-8, *38* the diameter d_1 of the shank is smaller than the minor diameter of the chamfer, and the surfaces of the shank and the chamfer being ground are overlapped by the grinding wheel.

28.5. Approach of Cutting Tools

To increase the efficiency and accuracy of the machining process the cutting tool should have an easy approach to the work surfaces. For this reason one must have a clear understanding of the machining operations, know the dimensions of the cutting tool and its fastening elements and the methods of mounting and clamping the work.

Figure 28-9, *1* presents a sheave of a V-belt transmission with a threaded hole *n* in the hub for the fastening screw. The shape of the part allows the hole to be drilled and threaded only through the bore *m* in the rim (Fig. 28-8, *2)* which should be provided in the design.

Some methods of making the hole *n* in a bracket (Fig. 28-8, *3*) are shown in Fig. 28-8, *4-6*.

When determining the inclination angle of a skew hole (Fig. 28-8, *5*), the drill chuck dimensions should be considered.

In the design of a pin-type fastening a cup-shaped part on a shaft (Fig. 28-8, *7*) it is impossible to drill and ream hole *n* for the pin and also insert the latter. In this case it is necessary either to provide hole *m* in the sheave rim (Fig. 28-8, *8*) or to change the position of the hub (Fig. 28-8, *9*).

Hole *n* (Fig. 28-8, *10*) in the leg between the flanges of a cylinder can be drilled through hole *m* (Fig. 28-8, *11*) or recess *q* in one of the flanges (Fig. 28-8, *12*).

When knurling the knob of the dial in the design shown in Fig. 28-8, *13,* the knurling roller cannot reach the base of the knob. The knob should be displaced from the dial to a distance *s* = 3-4 mm (Fig. 28-8, *14*) sufficient to let pass the cheek of the roller holder.

When the dial is large in diameter a composite design (Fig. 28-8,*15*) is preferable, allowing the use of a short and rigid roller holder.

Shaped slot *t* in the face cam (Fig. 28-8, *16*) cannot be formed as it is impossible for an end mill to approach the slot because there is a gear made integral with the cam.

To make the machining possible, the cam must be made detachable from the gear (Fig. 28-8, *17*).

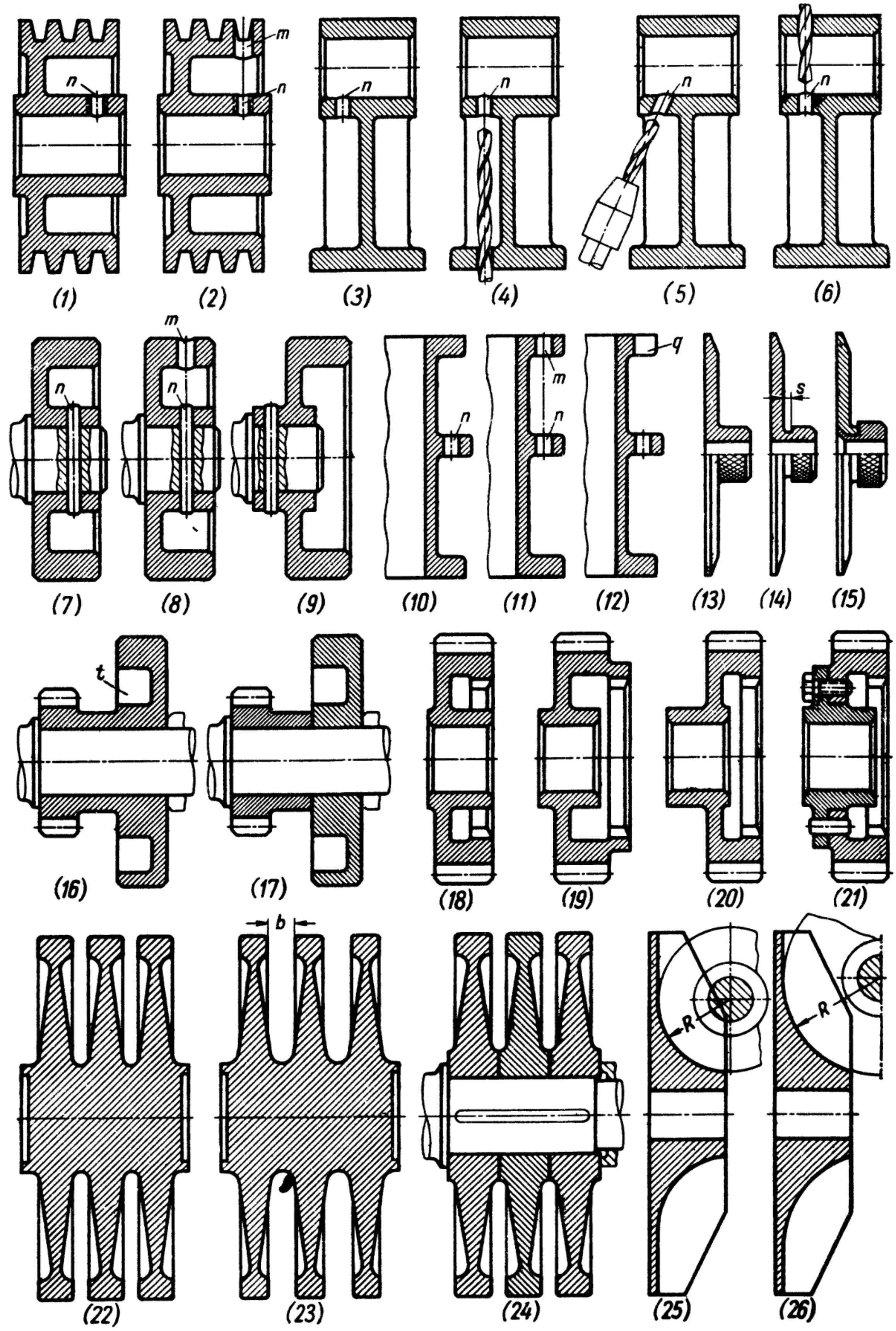


Fig. 28-8. Approach of cutting tools.

In the design of a gear with an internal splined rim (Fig. 28-8, *18*) the splines can be cut only by slotting. The more efficient and accurate generating method can be employed, if the splined rim is brought out beyond the hub (Fig. 28-8,*19*), or if the hub is displaced (Fig. 28-8, *20),* or else if a composite design is employed (Fig. 28-8, *21*).

The internal faces of the disks in the one-piece turbine rotor (Fig. 28-8, *22*) can be machined if the disks are arranged farther apart by increasing distances *b* and reducing the width of the disk rims (Fig. 28-8, *23*), or if a split design (Fig. 28-8, *24*) is employed.

It is possible to mill the impeller blades of a centrifugal machine (Fig. 28-8, *25*) if the radius at the base of the blades is increased to an amount that permits approach of a milling cutter (Fig. 28-8, *26*).

28.6. Elimination of Unilateral Pressure on Cutting Tools

When machining holes with cylindrical tools (drills, counterbores, reamers) it is necessary to prevent unilateral pressure on the tool, which impairs machining accuracy, intensifies wear and sometimes causes breakage of the tool.

In the design shown in Fig. 28-9*a* the tool at the section *m* cuts into the rough vertical wall of the product. During the process of machining the tool is subjected to a unilateral pressure, and the hole deflects to the opposite side. The design in Fig. 28-9*b* is better. The tool experiences a unilateral pressure only during the last machining stages.

Proper machining conditions will be ensured when the tool engages the metal with its whole surface. For this purpose the end of the hole should be positioned below the rough surface (Fig. 28-9*c*) or raised above it (Fig. 28-9*d).*

When spot-facing the fastening holes of a steel flange (Fig. 28-9*e*), cutting into the taper *n* which connects the flange with the cylinder walls will displace the tool mainly because the dimensions of the part do not allow the tool to be secured on a rigid arbor. If the shape of the flange is not changed, the flange has to be machined with a cutter of an increased diameter mounted on a rigid arbor advanced sideways (Fig. 28-9*f*). It is likewise possible to increase the diameter *D* and machine the flanges by turning (Fig. 28-9*g).*

Fig. 28-9*h-l* illustrates the arrangement of holes on a stepped surface. The holes intersecting the step (Fig. 28-9*h-j*) can be drilled only with the aid of a jig. It is possible first to drill holes through the previously machined surface *m* (Fig. 28-9*j*) and then turn the recess *n.* But this method disturbs the sequence of turning operations. It would be better to offset the holes to one or the other side of the step (Fig. 28-9*k, l*). In this case the drilling can be done without disturbing the sequence of turning operations. The offset should be large enough to prevent the formation of a thin partition between the drilled hole and recess (Fig. 28-9*l*).

Holes with intersecting axes should be avoided as far as possible. It is bad when the centre of the drill presses against the inclined wall of a transverse bore (Fig. 28-9*m).* It is somewhat better when the vertical bore is offset with respect to the axis of the cross drill by an amount *s* sufficient to centre the drill over the entire cutting path (Fig. 28-9*n)*.

It is good practice to drill the hole through the centre of the transverse hole or with an offset *e* relative to it (Fig. 28-9*o*). The maximum value of *e* with which the drill functions properly can be found from the formula $e = 0.2\,D\,(1 — d/D)$.

If *D* considerably exceeds *d* the vertical hole can be drilled first, and then the transverse one. In this case the amount of offset *e* is immaterial. It is also recommended to ensure cutting over the entire hole circumference at the exit of the tool.

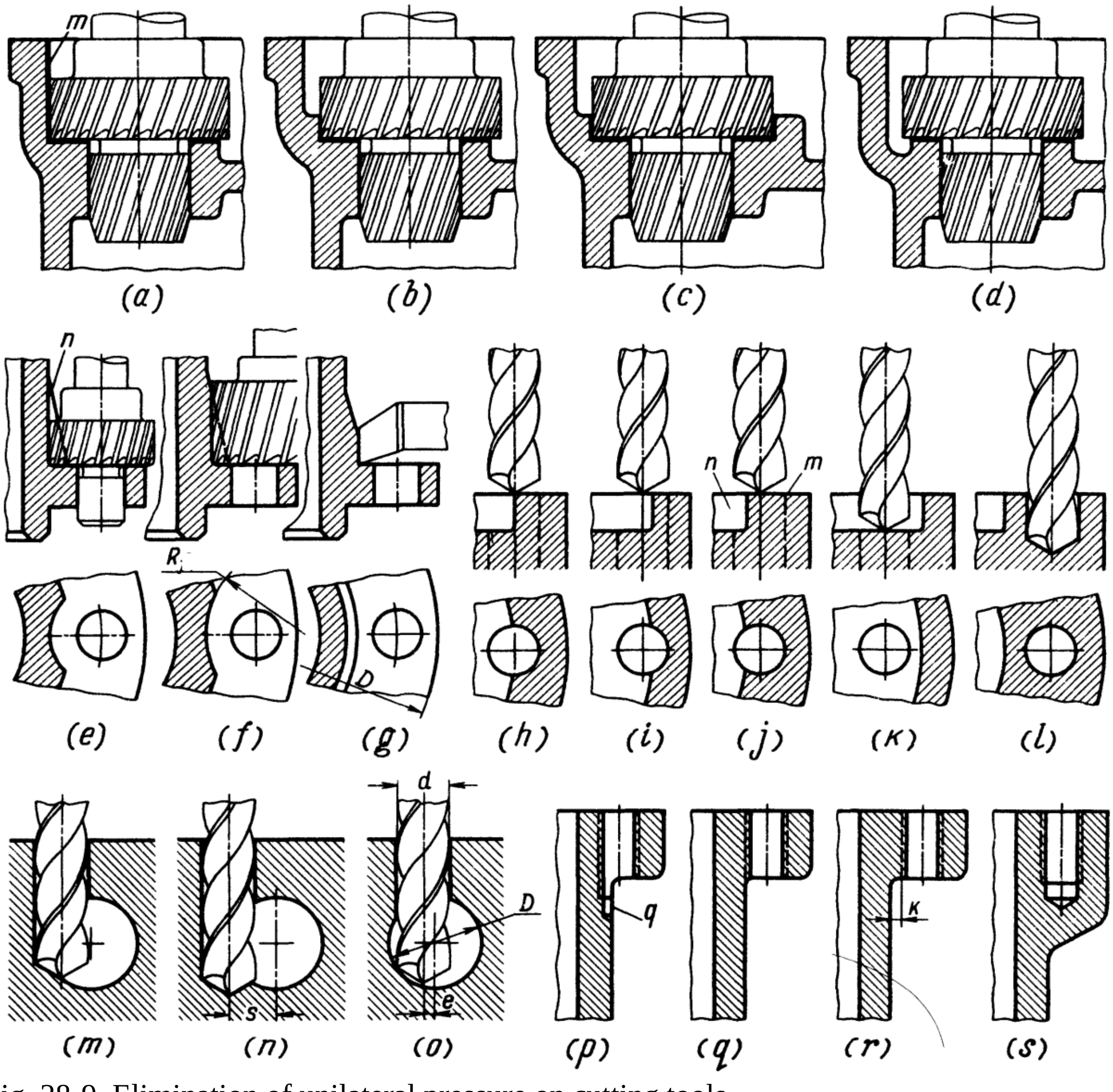


Fig. 28-9. Elimination of unilateral pressure on cutting tools.

In Fig. 28-9*p* the threaded hole in the flange in section *q* cuts into the wall of the part and the tool (drill and tap) is subjected to a unilateral pressure, which may cause its breakage. In the design shown in Fig. 28-9*q* the nominal dimensions of the hole allow it to be brought out beyond the wall limits, but the tool may cut into the wall due to production deviations (especially if the wall is rough). The tool will cut properly if the hole is removed from the wall to a distance *k* (Fig. 28-9*r*) sufficient to prevent cutting into the wall whatever its dimensional variations. If this is not possible the hole then should be arranged in a boss (Fig. 28-9*s*).

To obtain the required accuracy of machined surfaces, the first condition to be met is their sufficient and uniform rigidity. Otherwise, the less rigid portions are liable to sag under the action of the cutting force and will regain their former position after the cutting is done. This impairs the dimensional accuracy.

28.7. Centre Holes

Parts intended for machining on circular grinding machines or lathes, where the blank is mounted either between centers or in a chuck, with the free blank end being supported by the tailstock centre, are provided with centre holes.

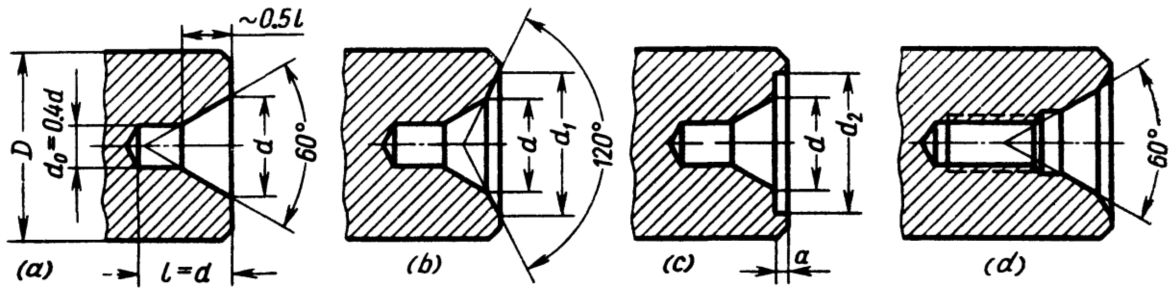


Fig. 28-10. Centre holes.

Standard types and sizes of centre holes are shown in Fig. 28-10. Centre holes with a chamfer (Fig. 28-10*b*) or recess (Fig. 28-10c) which protect the centering cone against dents are used when a part is mounted between centers during tests and also when it is necessary to keep the centers intact in case of returning or regrinding during repairs. Centers with a threaded hole (Fig. 28-10*d*) are used when a bolt has to be fitted in, and also (for heavy shafts) as a means for lifting the shaft.

The main parameter of a centre hole is the outer diameter *d* of the cone equal, according to the Russian State Standard, to 2.5, 4, 5, 6, 7.5, 10, 12.5, 15, 20 and 30 mm.

Diameter d_1 of the protective chamfer is made equal to (1.3 to 1.4) *d* (Fig. 28-10*b*) and diameter d_2 of the protective recess (Fig. 28-10*c*), to 1.3d. The depth of the recess *a* is equal to (0.1 to 0.15) d (the lower limit for holes of large diameter, and the upper one, for those of small diameter).The working surfaces of centre holes are made to Ra = 6.3….2.5 μm.

A blank can be installed between centers much more accurately and reliably if the maximum size of the centre hole, allowed by the design of the part, is used.

28.8. Increasing the Efficiency of Machining

Machining efficiency will undoubtedly increase if the maximum number of surfaces are processed on one and the same machine-tool, at one setting, in one operation with one tool utilizing all the possibilities of the machine on which the main operation is carried out.

In the design of a cylindrical shaft with an eye (Fig. 28-11*a*) the shaft and the adjacent end of the eye *K* are machined on a lathe. The surface *m* is milled to a templet. In design *b* the eye has a cylindrical form, and in design *c* the eye is spherical. All machining operations (except for drilling the hole and milling the faces *n)* are performed on a lathe, which appreciably increases the efficiency of machining.

Fig. 28-11*d* illustrates the shoe of friction clutch whose external surface *p* is to be turned. The fastening flange is of a rectangular shape and requires additional complicated milling operations. In the rational design *e* the flange is cylindrical, and the entire part is machined on a lathe as an annular blank which is then cut into sectors. To reduce waste the length of the sectors should be such as to accommodate them a whole number of times in the circumference of the blank including the slitting saw thickness.

In the flanged shaft with a square flange (Fig. 28-11*f*) the side faces of the square are milled to a templet. The shaft with a cylindrical flange (Fig. 28-11*g*) is machined wholly on a lathe.

The number of resets should be reduced to the minimum on each machine tool so that the maximum possible number of surfaces can be machined in one setting. Fig. 28-11*h* presents an adapter with two centering bores of different diameter and two rows of offset fastening holes. A slight design change (Fig. 28-11*i*) makes it possible to through-pass machine the centering bores and fastening holes simultaneously.

The design of the slotted washer (Fig. 28-11*j*) is poor. The hub *s* protruding into the washer hampers a through-pass machining of the slots which in this instance can be machined only by a unproductive slotting operation. In the rational design *k* the slots are through milled.

In a four-jaw driver with radial jaws (Fig. 28-11*l*) the side faces of the jaws are milled in four settings, the blank being each time rotated through 90°. The surfaces *t* between the jaws are planed or milled to a templet.

In design in Fig. 28-11*m* the radial jaws are replaced by side one milled in two settings. At each setting two jaws are machined simultaneously. The working faces of each pair of jaws are through-pas machined and the accuracy of the arrangement of the jaws is therefore increased. The same advantage can be derived if radial slots (Fig. 28-11 *n*) are replaced by side ones (Fig. 28-11*o*).

The number of slots and their layout should agree with the conditions required by through-pass machining allowing the maximum number of surfaces to be machined at the same time.

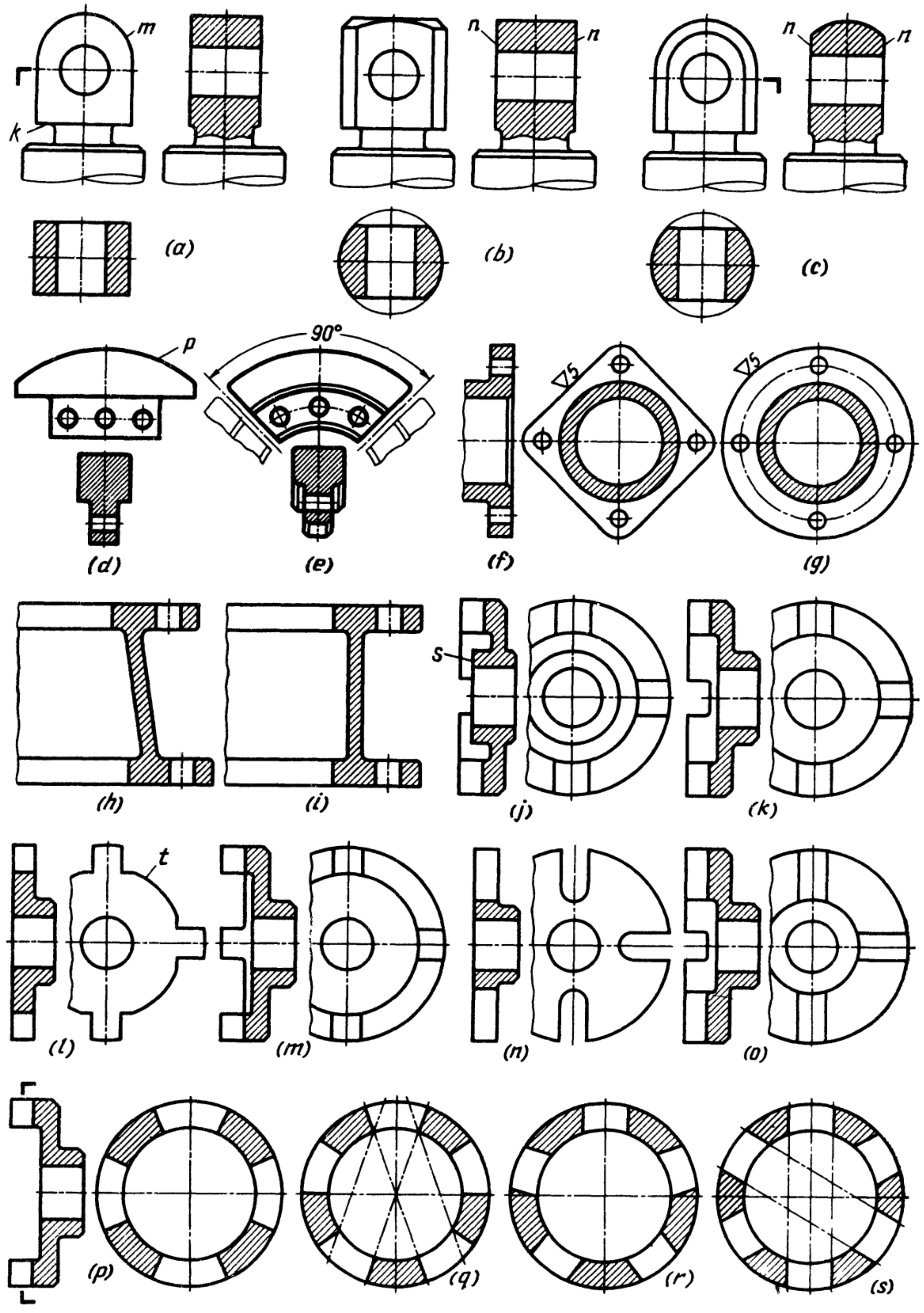


Fig. 28-11. Increasing of the machining efficiency.

If the faces of slots are located radially the number of slots should preferably be uneven (Fig. 28-11*q*). This makes it possible to through pass machine two opposite faces simultaneously (dash-and-dot lines] When the number of slots is even (Fig. 28-11*p*) machining is inconvenient and non-productive.

Conversely, in the case of **straight-sided slots** through-pas machining requires an *even* number of slots (Fig. 28-11*s*). Machining is difficult when the number of slots is uneven (Fig. 28-11*r*).

Machining at an angle to datum surfaces should be avoided This complicates setting up of the machine-tool because the product has to be mounted on swivel tables or attachments.

Fig. 28-12*a*, *c* shows examples of unsound arrangement of hole in frames. Machining is considerably simplified if the holes are parallel (Fig. 28-12*d*) or normal (Fig. 28-12*b*) to the datum surfaces.

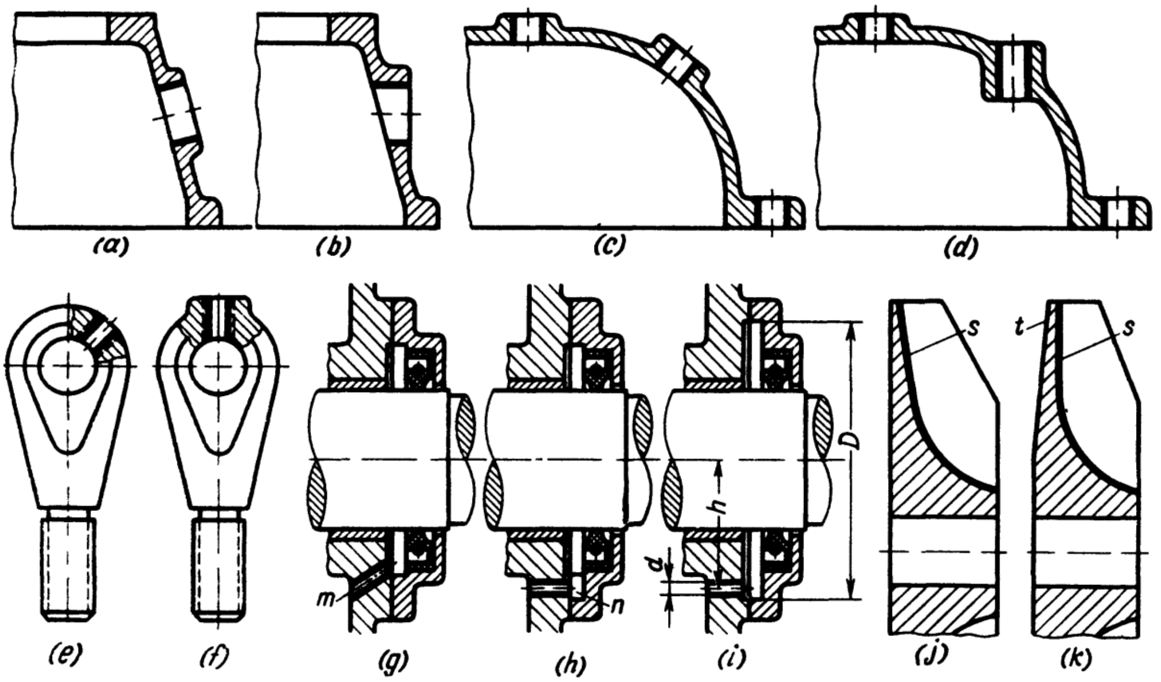


Fig. 28-12. Elimination of machining at an angle.

In the design *e* of an eye (Fig. 28-12) the threaded hole for an oiler is positioned at an angle, which means that a jig is necessary for drilling the hole. In design *f* the hole is positioned on the axis, an can be drilled and threaded when the eye is turned on a lathe.

In the design *g* in Fig. 28-12 of a sealing unit the inclined drain hole *m* can be made parallel to the shaft axis if a slot *n* is milled in the seal cover (Fig. 28-12*h)* or if the diameter of the cover recess (Fig. 28-12*i*) is increased to $D = 2h + d$ (*h* is the distance of the drain hole to the shaft centre and *d* the drill diameter).

In the impeller of a centrifugal machine (Fig. 28-12*j*) the thickening of the impeller disk towards the hub required for better strength can be attained if the surfaces *s* between the blades are inclined This makes it necessary when milling for the impeller to be held in a fixture on a canted centering pin. In the design *k* in Fig. 28-12 the disk can be thickened towards the hub if the back surface *t* of the impeller machined by turning is slightly tapered. The surfaces *s* between the blades are milled.

Machining productivity can appreciably be increased by the use of combination tools which simultaneously machine several surfaces (core drills, block cutters, sets of milling cutters, etc.).

The bracket (Fig. 28-13*a*) processed over the external *m* and internal *n* side faces of the eyes and also over the surfaces *o* of the fastening bosses is machined with a set of plain milling cutters in two settings. The first setting is used to machine the side faces *m* and *n* of the eyes with a set of three milling cutters (Fig. 28-13*d*). Then, the part is swivelled through 90° and the boss surfaces *o* are milled with a set of two cutters (Fig. 28-13*e*).

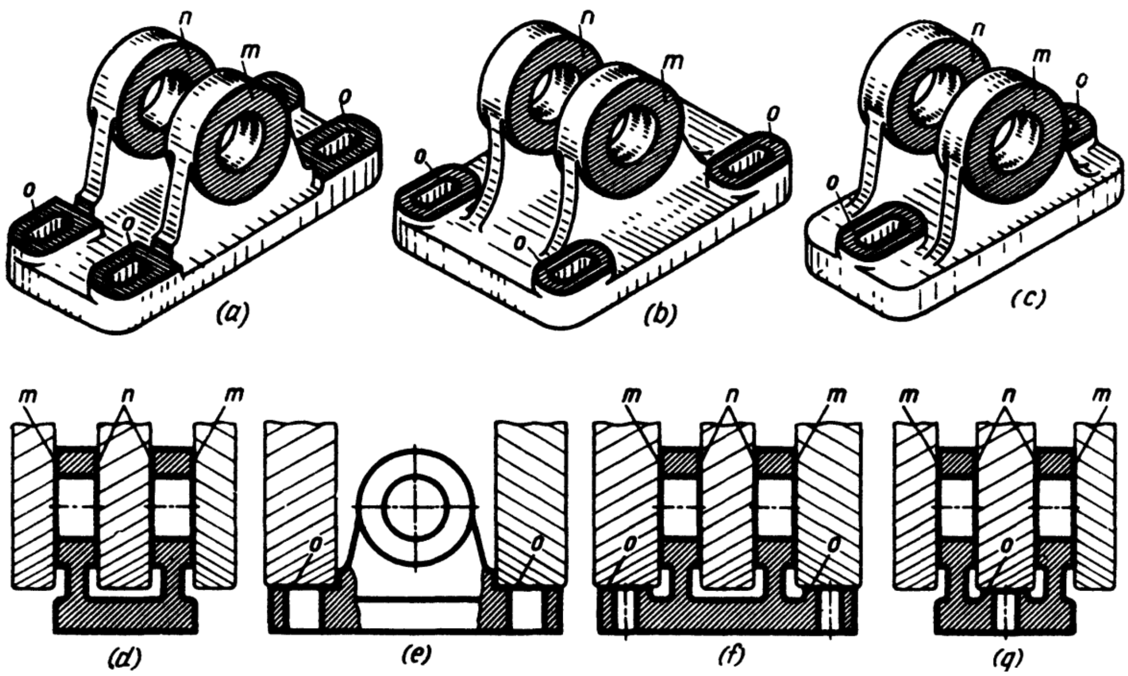


Fig. 28-13. Machining a bracket with a set of milling cutters.

Dislocation of the bosses in relation to the eyes (Fig. 28-13*b*) allows the part to be machined in a single setting with three milling cutters. The cutter side faces (Fig. 28-13*f*) cut the surfaces *m* and *n* of the eyes, and the peripheries of the two outer cutters process the surfaces *o* of the bosses at the same time.

In the very compact design *c*, the fastening bosses are arranged between the eyes and are machined by the periphery of the internal cutter (Fig. 28-13*q*) at the same time as the internal side faces *n*.

28.9. Multiple Machining

In large lot and mass production, the tendency is to machine parts in groups to a preset operation with establishment of the blanks in quick-acting machining fixtures.

Consecutive machining (Fig. 28-14*a*) reduces handling time (the time needed to mount the blank and adjust the machine tool).

Parallel machining (Fig. 28-14*b*) reduces machining time in proportion to the number of blanks being simultaneously machined.

Parallel-consecutive machining (Fig. 28-14*c*) is the most productive.

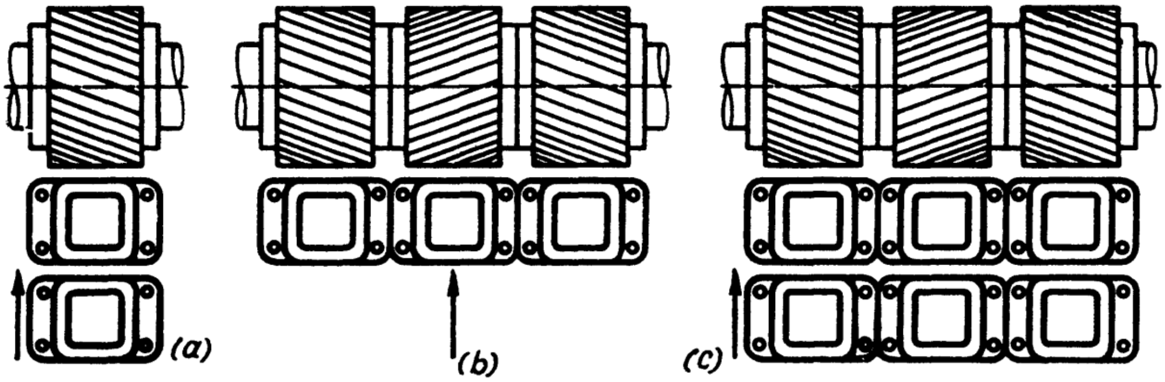


Fig. 28-14. Diagrams of group machining.

For all these methods through-pass machining is obligatory.

28.10. Heat-Treatment of Ferrous Metals and Alloys

Heat-treatment whether concerning steel or cast iron, is a vitally important job and one which demands particular attention. It will be seen that the forms of heat-treatment practiced vary widely and whilst it is necessary that each one should be thoroughly understood, it is equally important that the particular treatment to which any material may be subjected, is duly appreciated. It is quite true to say that the majority of failures which occur in finished components can be traced back to either faulty or incorrect heat-treatment.

In the first place it would perhaps be of benefit to outline as simply as possible, the reason why heat-treatment is necessary. It may seem rather strange that where certain materials have to be softened, others have to be hardened; in some cases the treatment precedes machining and in others it is subsequent to the machining operations. All this is largely connected with the machinability and the particular application or function of the finished component. For example, the ordinary low and medium carbon steels can be readily machined in their normal supplied condition. The high tensile and tool steels, and many alloy steel and iron castings, cannot in most cases be subjected to any machining operation other than grinding, until the material, whether in its rolled, forged or cast condition has been suitably softened. Whether or not machining operations have to be performed, most steel forgings or castings are too brittle and require some form of heat-treatment before they can be used. The treatment employed may consist of annealing or normalizing.

Then, there is the class of steels used principally for tools, cutters, etc., consisting chiefly of high carbon and other special alloy steels, which, after the necessary forging and machining operations, have to be hardened and then tempered. The heat-treatment in this case has to make the steel as hard as possible whilst retaining sufficient toughness to avoid failure due to chipping and cracking during service. After the heat-treatment, only grinding, honing or lapping operations can be carried out.

Another class of heat-treatment concerns **case-hardening**. In this instance the application of the particular part determines that the outside surface of the steel must be very hard and resistant to wear. The hardness in this treatment is limited to the outside skin (or case) of the material, the inside core being left in its softer and more ductile state, in which condition it is better able to withstand stress and shock loads. The methods of obtaining this surface or case hardness are numerous.

It is perhaps advisable to mention a few of the alloy steels which, as well as the very low carbon steels, are not responsive to ordinary heat-treatment methods. The very low carbon steels, those containing not more than 0.2 per cent carbon, cannot be hardened in the ordinary way by heating to a red heat and quenching. They can, however, be surface hardened by some of the case-hardening processes. Some of the alloy steels are also regarded as non-heat-treatable steels. One example is manganese steel where the manganese content exceeds about 10 per cent; another is the high percentage nickel-chromium steels with a nickel content of 5—10 per cent and chromium ranging from 10 to 20 per cent.

The aluminium alloy steels require careful treatment; such steels cannot be normally forged but they can be very satisfactorily surface hardened by the nitriding process.

Simple Structure of Steel. It is quite easy to imagine steel as a hard, solid material which is homogeneous and unchanging. This, however, is far removed from fact, as steel must be accepted as being rather complex as to chemical combination, and amenable to and readily changed by various forms of heat-treatment. There is no intention to delve into the behavior of carbon steels during certain stages of heat-treatment, and from this, perhaps, to secure a grasp of the peculiarities of other materials.

Steel in its simplest form can be considered as an alloy of iron (ferrite) and iron carbide. The pure iron is almost white in appearance and very ductile and malleable, whereas the iron carbide constituent is brittle and exceptionally hard. The carbon is not in a "free" state as is found in cast iron but is "combined" with some of the iron to form iron carbide or "cementite". In this state it is discernible under a microscope if the surface of the steel has first been suitably polished and etched.

When this cementite is formed it mixes intimately with the ferrite and produces what is then termed "pearlite". As more carbon is added or transferred more pearlite is formed until the structure becomes wholly pearlite at 0.87 per cent carbon. By heat-treatment it is possible to dissolve some of the iron carbide and form what is termed a "solid solution" of carbide in iron, referred to as "austenite". This can take place at a certain elevated temperature (later referred to as a critical point) but as the metal is still in a solid state it is identified as a "solid solution" so as to distinguish it from changes which can be affected with steel in a molten state. In hardening steel by heating and quenching it is a question of bringing about this change and then trapping the iron carbide in solid solution by means of quenching. Slow cooling, as practiced in annealing, allows the iron carbide to separate out again or segregate.

Heat and Temperature. These two words are frequently misunderstood and misused. **Heat** may be expressed as an amount or a quantity. For example, the amount of heat required to raise a bar, say 50 mm, in diameter and 300 mm long from cold to 600 °C would be greater than the amount required to raise a 20 mm diameter bar of the same length to the same temperature of 600 °C. The amount of heat stored in the 50 mm diameter bar would be greater than that in the 20 mm diameter bar when they were both at the same temperature; and a longer time would be required for the 50 mm diameter bar to lose its heat if allowed to cool naturally to room temperature. The **temperature** may be defined as the degree of hotness on a scale of comparison. (There are two scales of comparison—Celsius and Fahrenheit.). Another example coupling both terms may be given. The sparks are at high temperature but they do not contain sufficient heat and quickly lose it when in contact with a cooler body. Larger fragments of scale and slag would produce burns, even if at a lower temperature, as they are greater in volume and contain more heat.

Quenching and Tempering. The term "**quenching**" refers to the process of cooling metal rapidly from a higher temperature. The medium used for quenching may be one of the following, set out in the order of increasing severity: air, oil, hot water, cold water, salt and other special solutions, mercury.

The more rapid the rate of cooling or quenching from a given temperature, the harder will be the steel. Very rapid rates of quenching cannot always be employed as such a quick change in temperature is conductive to cracking and distortion. This is affected to some extent by the particular steel and the shape and size of the part undergoing treatment.

It is very essential in order to secure consistent heat-treatment results that the quenching is carried out in such a manner as to ensure that the same conditions exist for each component or batch being treated. Where frequent quenching is being done or where large batches are being quenched in one tank, arrangements have to be made to keep the quenching medium circulating freely. Coolers have often to be incorporated to maintain the temperature of the medium within reasonable limits, as each part or batch introduced normally has the effect of increasing the temperature. Where air is used, it is at normal room temperature and may be either natural or forced, the latter resulting in a more rapid quenching. Salt solutions and mercury are used chiefly for the **hardening** of special tools and cutters.

A certain amount of the initial hardness obtained after the first quenching must be sacrificed in order to secure a certain degree of toughness necessary to enable the tool to withstand any shock or stress load encountered during use. This second heat treatment, called **tempering**, is effected at a much lower temperature.

Improved mechanical properties, including increased strength and hardness and resistance to wear, can be obtained by the heating, quenching and tempering of cast iron just in the same way as steels. The temperature and quenching media used must be assessed according to material and relative sections. By the addition of nickel or by reducing the rate of quench, it is possible to obtain equivalent results at much lower and safer temperatures. Oil quenching can be substituted, or, in some cases, air hardening may suffice. The temperatures for hardening and tempering must be held close to the limits specified for the particular iron, whether gray or alloyed.

Annealing. This is a process to which steel parts or stock may be subjected in order to produce a much softer state to facilitate machining or other forming operations or to relieve the stresses which have resulted from some previous mechanical treatment, such as rolling, forging, pressing or drawing. Steel castings may similarly be treated to remove the coarseness of grain and relieve the stresses imposed by unequal cooling. Some castings of particularly unequal section have to be introduced into the annealing furnace whilst still red hot, because if they were allowed first to cool cracking would inevitably result.

Bright annealing is a variation of a method of the annealing processes where bright steel is being treated and is desired to preserve the surface, and where pickling and other cleaning operations would otherwise be necessary. Normally the surface of annealed bright steel would be discolored and covered with a scale due to the effect of the oxygen-bearing: atmosphere present in the furnace chamber. To avoid this, an artificial atmosphere has to be created and the furnace chamber suitably sealed, so that this condition can be maintained until the temperature of the parts being treated has fallen to a safe value. Various gases are employed for the purpose according to the nature of the work.

A full annealing treatment may be given to relieve internal stress and increase machinability. For ordinary gray cast iron, a heating temperature of 750—800° C is necessary to convert the combined carbon into a free graphitic state. In the case of pearlitic gray cast iron it is necessary to convert the matrix into a ferritic state.

The heating should be gradual and continued for several hours, the time varying according to thickness and followed by a very slow rate of cooling. Annealing in this way gives the maximum relief of stress and produces the softest state possible, but unfortunately is accompanied by a big reduction in tensile strength. In some cases, the tensile strength may be reduced to less than a third of its original cast value and this factor must be borne in mind when stressing annealed castings. Cast irons rich in phosphorus do not respond to this treatment, as the hard phosphide eutectic constituent is not affected by this heat-treatment.

Normalizing. This heat-treatment process is carried out, not so much to produce a soft ductile state, but chiefly to relieve the stresses set up by rolling, forging or other mechanical treatments. Castings, particularly those of small and regular shape, may be normalized to relieve the cooling stresses, and electrically welded components are similarly treated when their size and shape permit. The parts to be treated are heated in the same manner as in the annealing process but the cooling takes place in air. For this reason the parts to be normalized should not vary greatly in section, as cooling is certain to be more rapid where the section is thin or where projections or fins occur. Castings which have widely varying cross-sect ions are more satisfactory when annealed.

Steel treated by the normalizing process has a relatively fine grain, whilst possessing a greater tensile strength and higher yield point than a similar steel treated by annealing.

Patenting. This is really an annealing process which is applied especially to high tensile steel wire of the high carbon type after either drawing or sometimes during the drawing operations. Drawing, like other mechanical working processes, has a work-hardening effect upon the steel and sets up a condition of stress between skin and core. Where considerable reductions have to be made, one or more annealing operations may be necessary before the wire has reached its final gauge size on leaving the last die.

A considerable increase in ultimate tensile strength can be obtained from wires which have been patented and drawn as compared with wires of identical steel which have been annealed and drawn. The increase in reduction of area values is also considerable but with very little change in elongation.

Hardening. The first stage of this treatment consists of hardening by heating to the temperature which is in accordance with the particular carbon content of the tool being treated; then, after a suitable time has been allowed for soaking, quenching in oil or water is required. Electric, oil fired or gas fired furnaces are most satisfactory for heating and should preferably be fitted with a pyrometer to give a continuous indication of the furnace temperature. Heating should be gradual and particularly so where tools of large section are dealt with. Some furnaces are made with a pre-heating chamber which can be used for preliminary heating. The time allowed for soaking is determined by the size of the tool or part and normally would not be less than 5 min. for, say, a % in. square tool and about 15 min. for a tool 1 in. square. The heating capacity of any type of furnace must, of course, be taken into account in determining the soaking time allowed.

Quenching, which follows the heating, is in most cases effected in oil. Water is sometimes used in quenching smaller tools and although producing a greater degree of hardness, is more likely to cause cracking. Larger section tools are more susceptible in this respect. The temperature of the quenching media can play an important part in the final result and care must be taken to ensure that the temperature of the quenching bath does not become progressively higher as successive batches of tools are introduced into it for quenching. Where large quantities are being treated continuously, the bath should be sufficiently large to allow adequate surface cooling, or an additional cooler or cooling pipes should be installed.

The manner in which the parts are introduced into the quenching media is also of importance. Long parts should be plunged in vertically so as to minimize distortion. The parts should in any case be moved about in bath until cool and not simply thrown in and allowed to settle at the bottom of the bath. Large tools if treated in this manner, may quite likely come out soft, as the initial quench simply affects the outside, leaving the inside core hot. The heat of the core immediately starts working outwards, bringing the whole tool up again to a fairly high temperature. The oil surrounding the tool would only circulate by convection and therefore be quickly raised in temperature and only a very slow cooling would then take place. Where large batches of similar tools are to be treated, some form of tray or basket is usually made into which they can be grouped or stacked and suitably manipulated during quenching.

High carbon steel after this heating and quenching treatment is left in a state of extreme hardness but is much too brittle to be of any practical use and so a secondary process, known as tempering must then follow.

Case-Hardening. This is a process by which the outside case or surface of a carbon or other alloy steel may be hardened to give a suitable wearing or bearing surface without affecting the inside core. The core can be left in a tough and ductile state necessary to withstand the loads imposed upon it, a condition which would not exist if the hardness was the same through the whole structure. Case-hardening is used in making many objects, especially automobile parts, such as gears, crankshafts, pins, and the like. The depth of the case depends upon several factors (including material, time, and temperature) and may vary from a few thousands of an inch to about 0.15 in. The depth of the case necessary for a particular component depends upon its application with respect to the nature and extent of the load conditions, and with respect to the machining allowance; the latter must take into account the extra machining by grinding, made necessary by distortion. Heating temperatures, methods of quenching and shape of the part to be treated are the factors which particularly affect the amounts of distortion.

Carburizing. A considerable proportion of case-hardening is effected by the carburizing process which is particularly suited to the case-hardening of low carbon steels as well as some of the other alloy steels. The low carbon steels, can, with suitable treatment, have their outer cases enriched in carbon to over 1.0 per cent, so that when quenched from a temperature above the upper critical point hardening of the outer case results. Small components are most easily treated by this process as they can be packed in suitable boxes which greatly facilitates charging and this is more economical with regard to the quantity of carburizing media required.

The carburizing material consists of bone or wood charcoal, charred leather, or petroleum coke to which is added barium carbonate, sodium carbonate or some other form of energizer to ensure a more rapid action.

Cyaniding. This is another case-hardening process and in this method, a liquid case-hardening medium is used. The parts selected for treatment by this process are usually small, such as gears, pinions, set-screws, ball and roller bearings and races, etc., and other such applications where a light case is adequate.

The case hardening medium used may be either sodium cyanide or potassium cyanide. These are highly poisonous chemicals in either solid or gaseous state and extreme care must be exercised throughout the process.

Nitriding. Another method of case-hardening steel is by the process known as nitriding. This is used for many parts of automobiles, airplanes, and machinery because it gives a surface which is much harder than that produced by case-hardening with carbon, and also because it requires no rapid cooling after nitriding in order to produce the hardness. Rapid cooling (quenching) tends to distort some shapes of carburized parts. Nitriding is performed by heating the steel for several hours or even days in an atmosphere of ammonia at 510 to 535° C, which is lower than employed in carburizing. This results in an absorption of nitrogen by the surface of the steel, which makes it hard without any further heat-treatment. Many precautions must be taken in nitriding, and it is an operation requiring experience and skill.

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