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ACCEPTANCE TESTS FOR MACHINE TOOLS [1]

prepared
by

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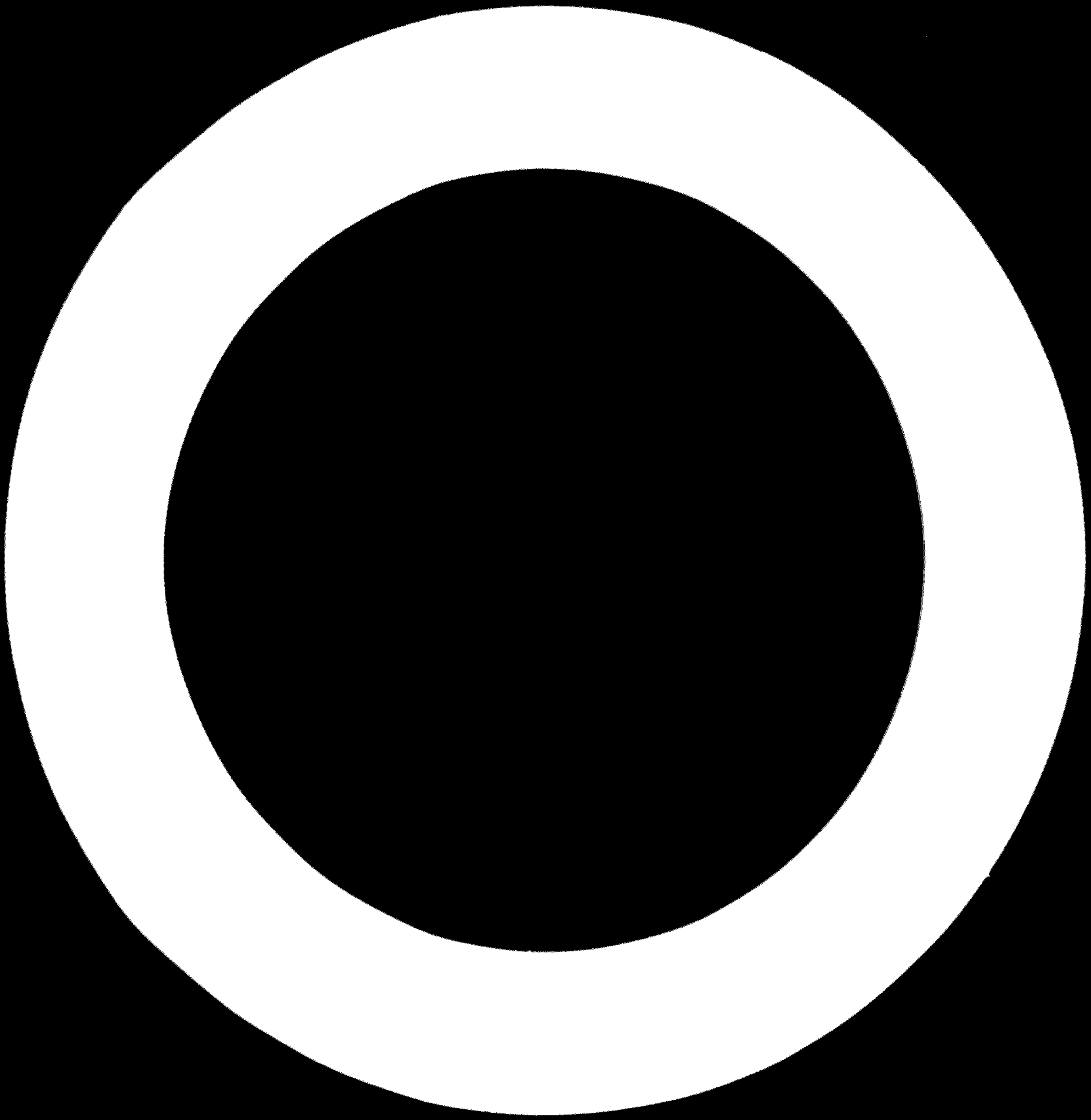

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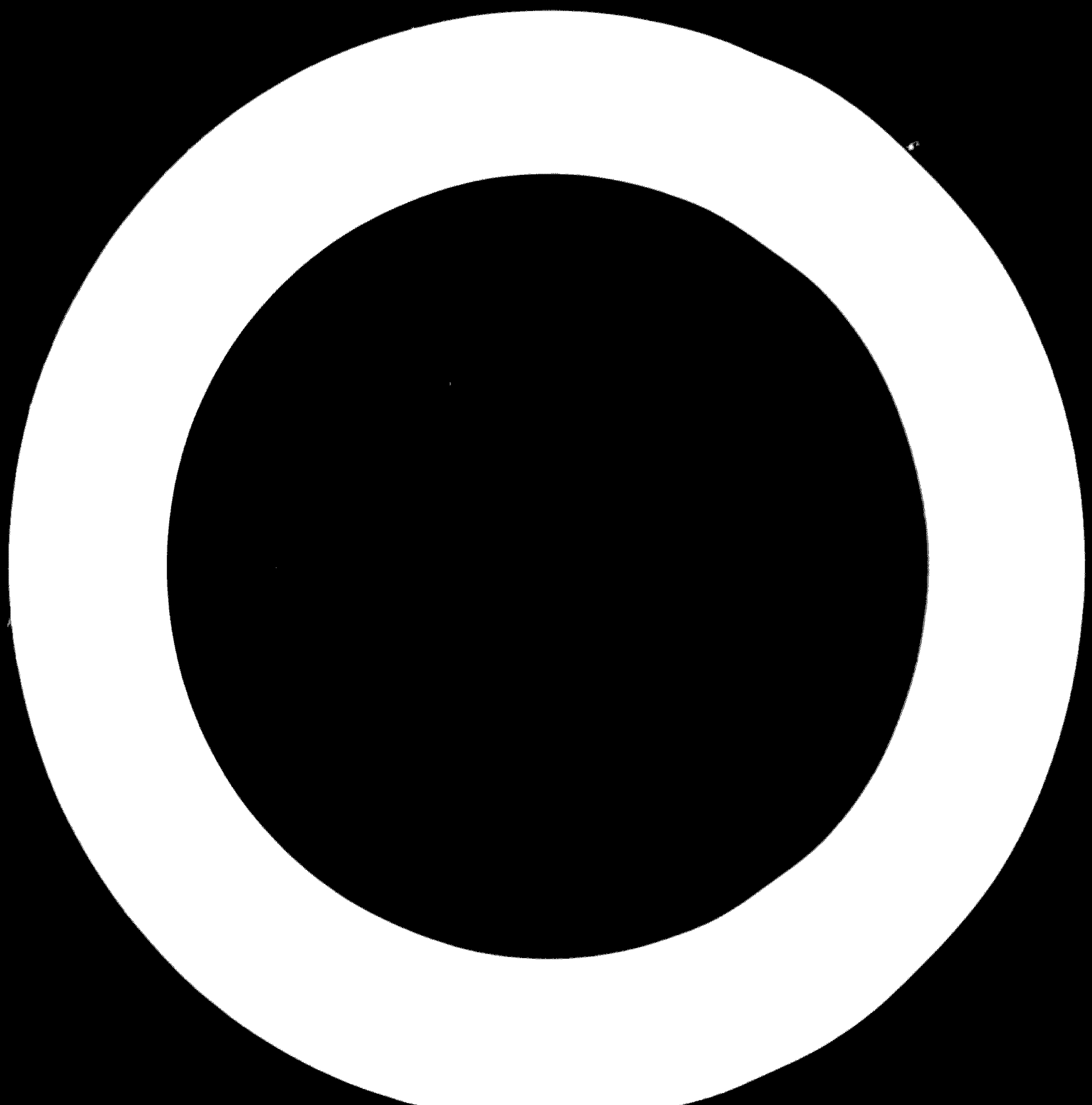

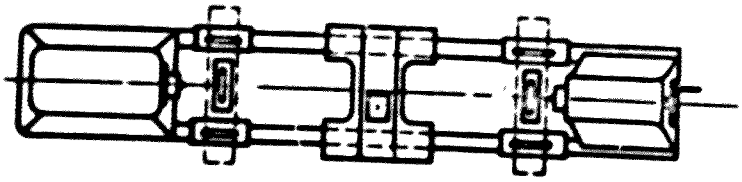

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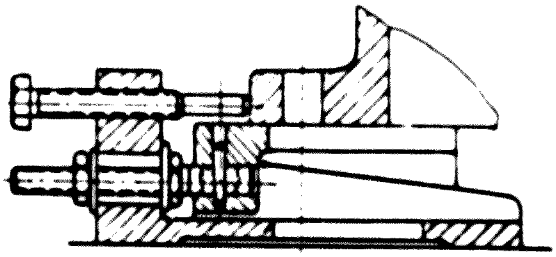

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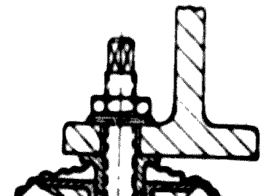

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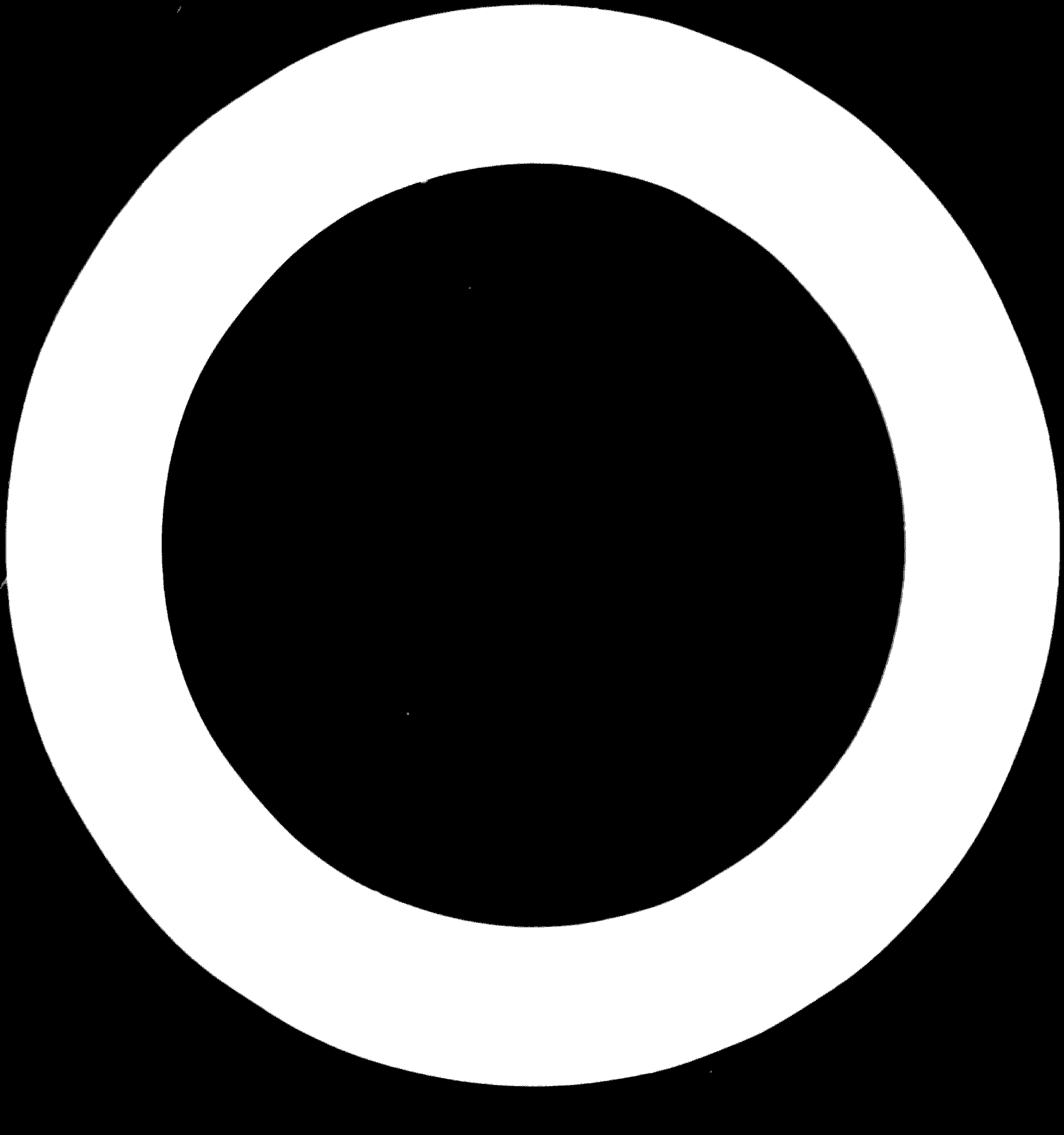

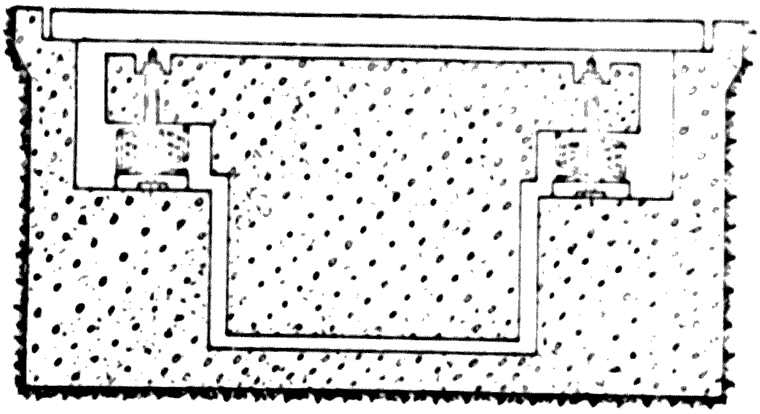

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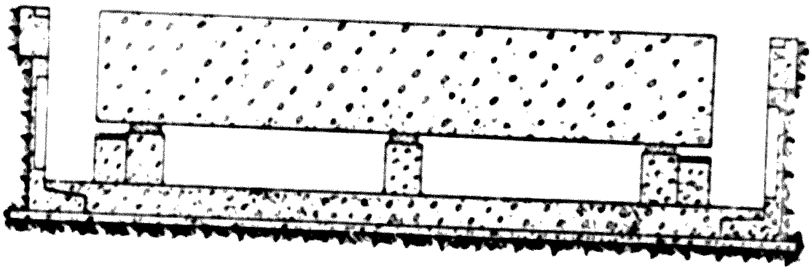

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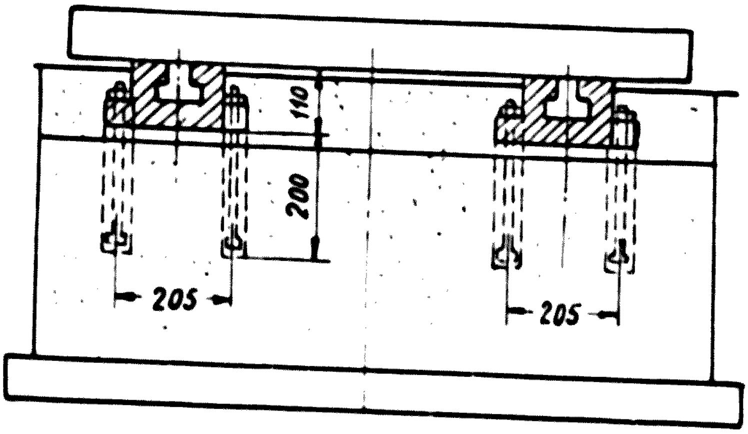

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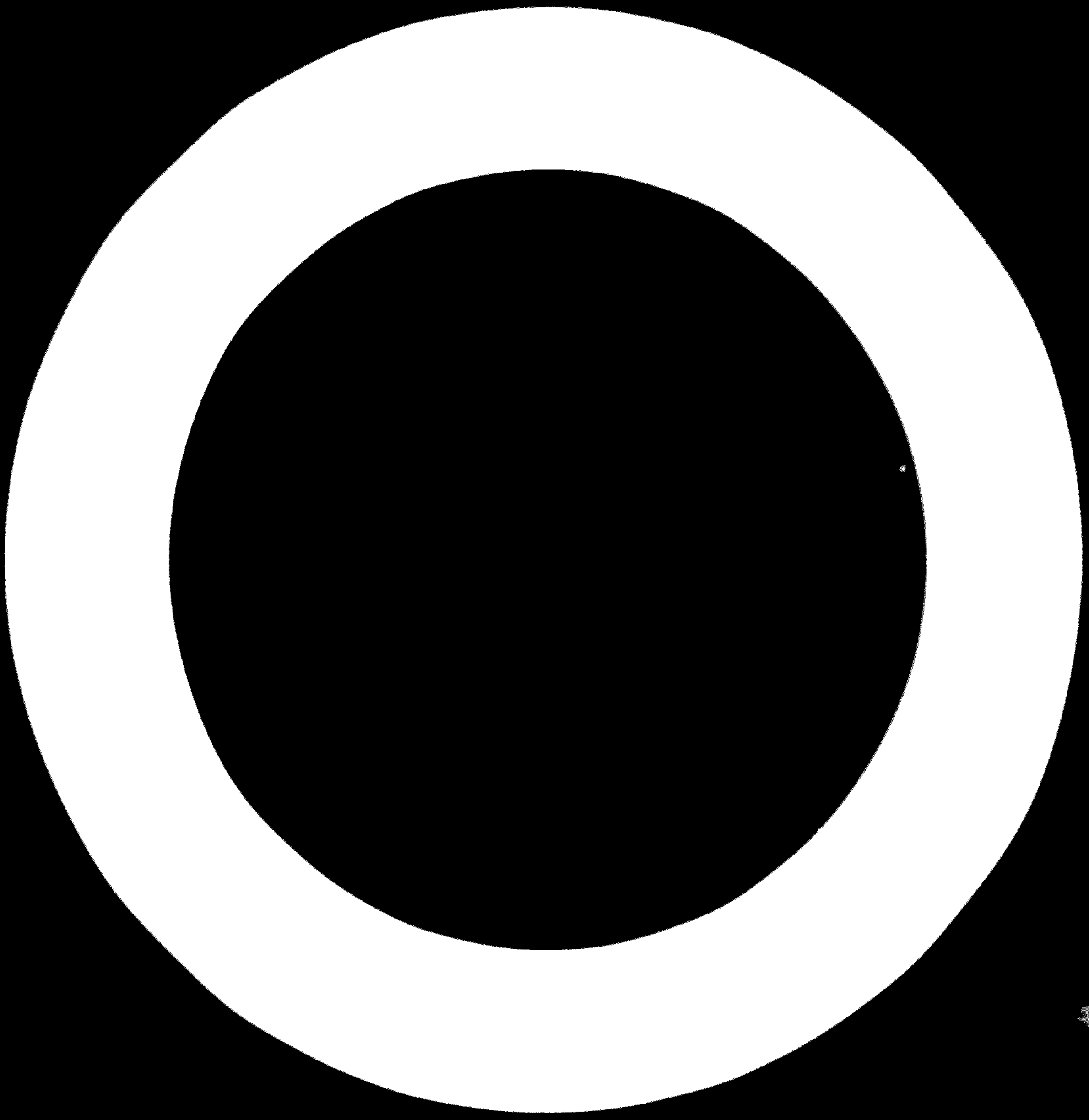

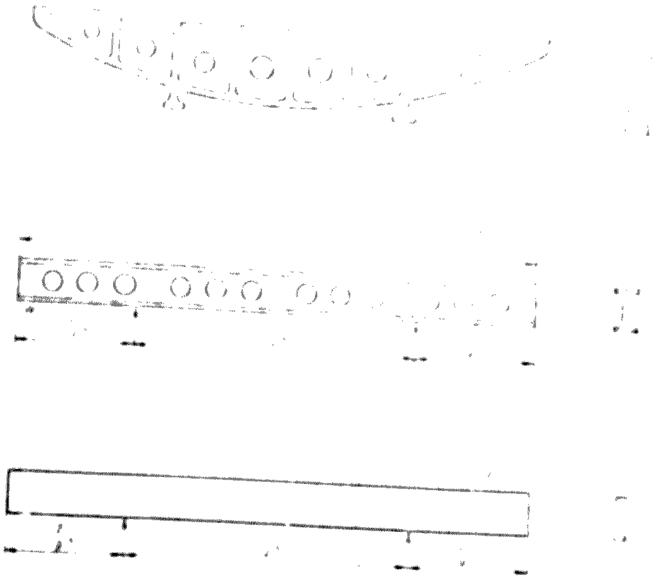

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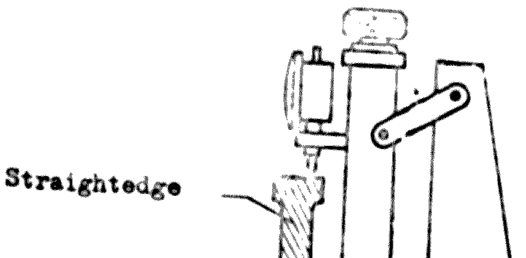

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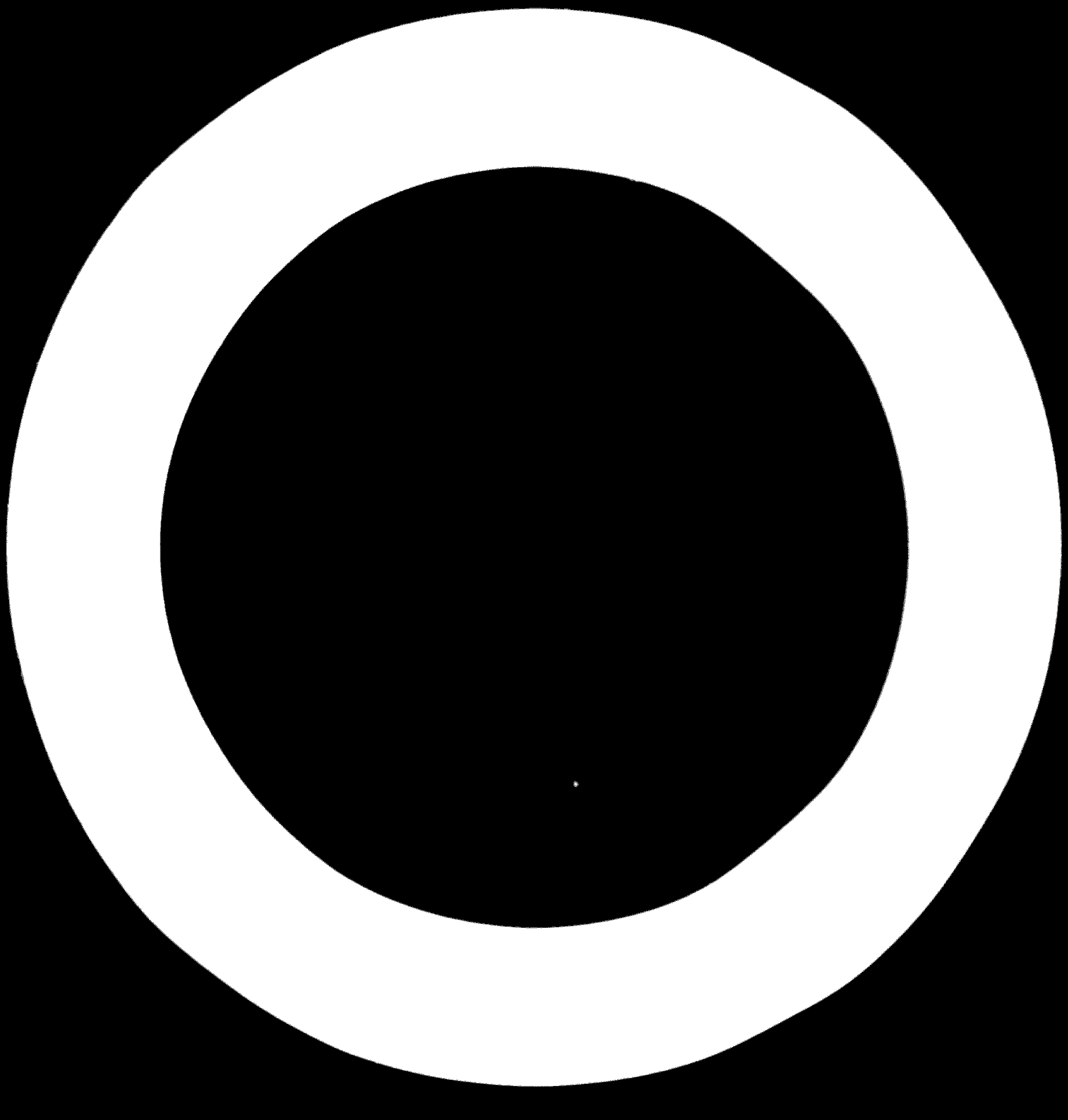

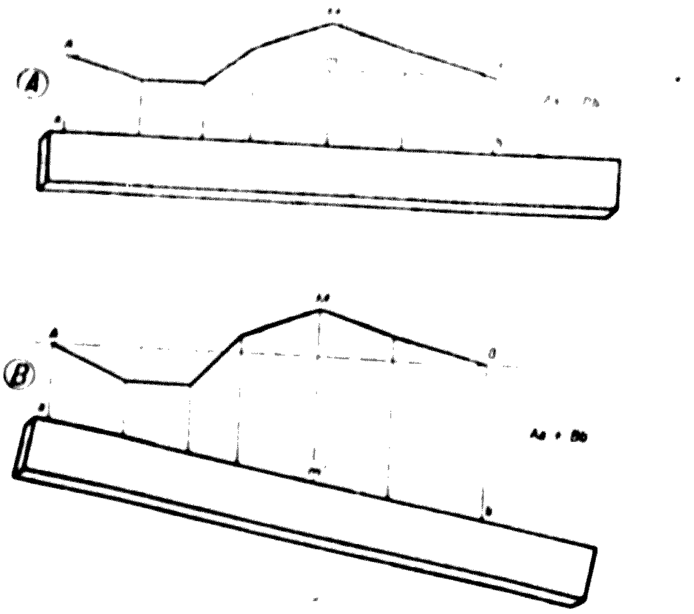

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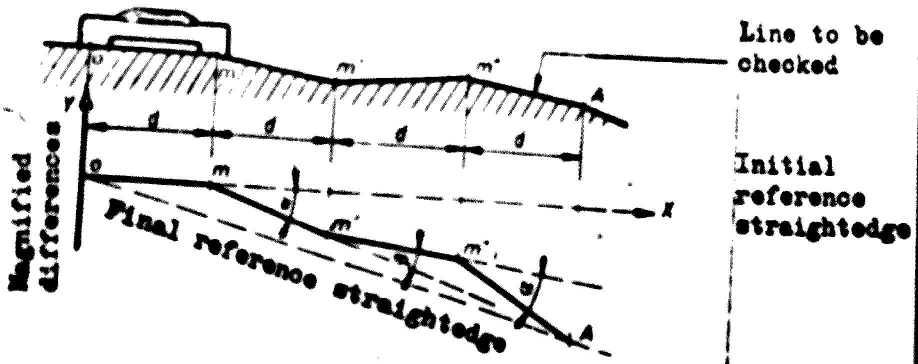

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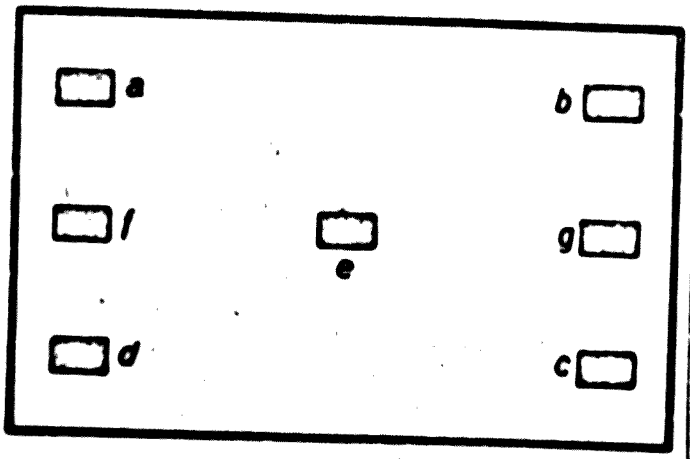

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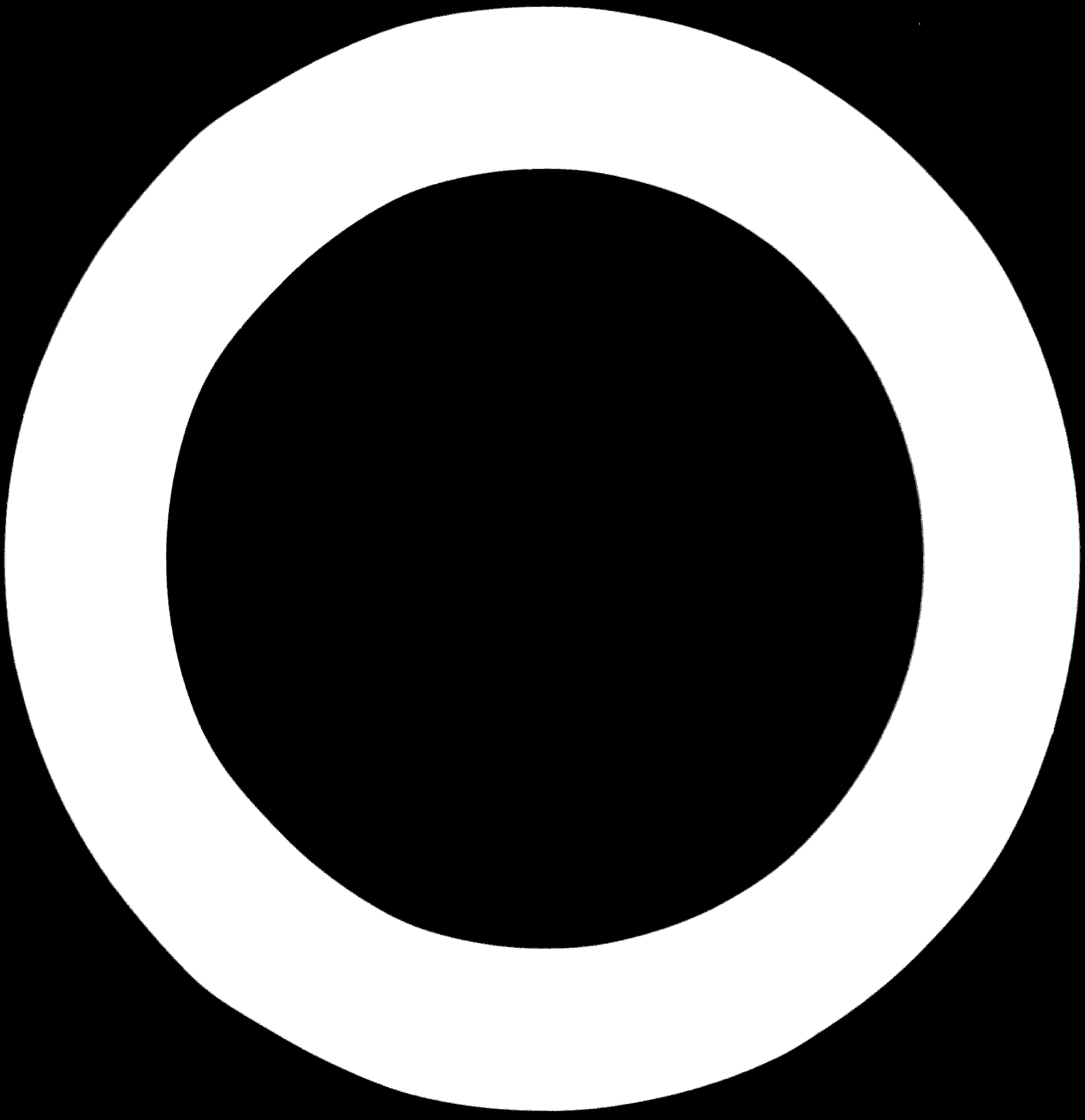

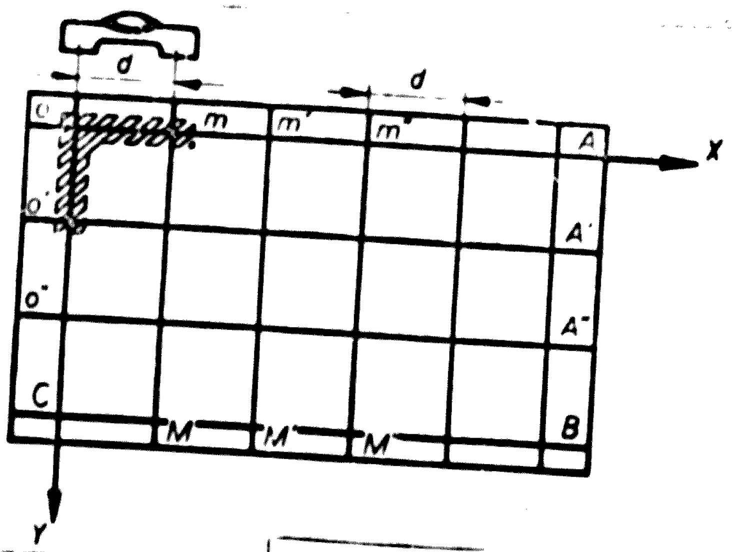

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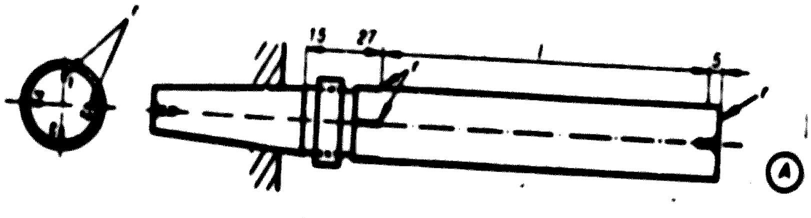

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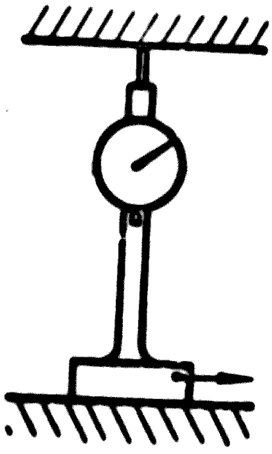

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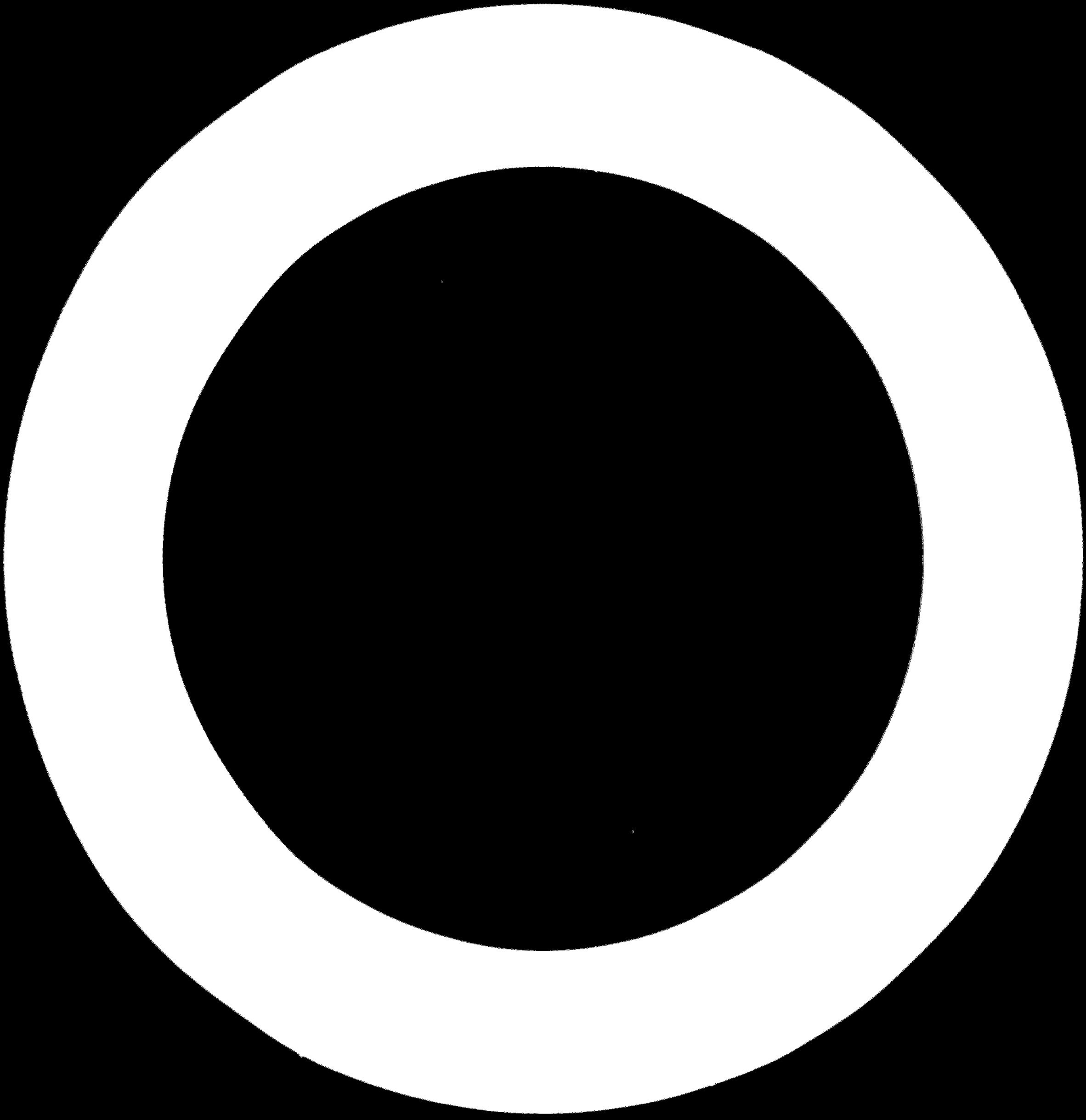

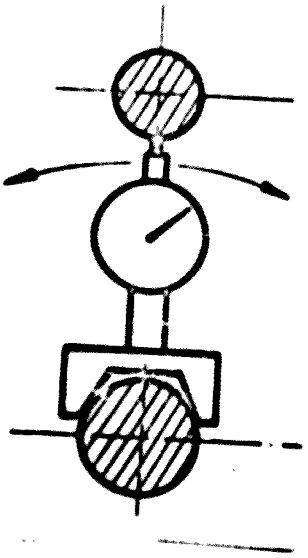

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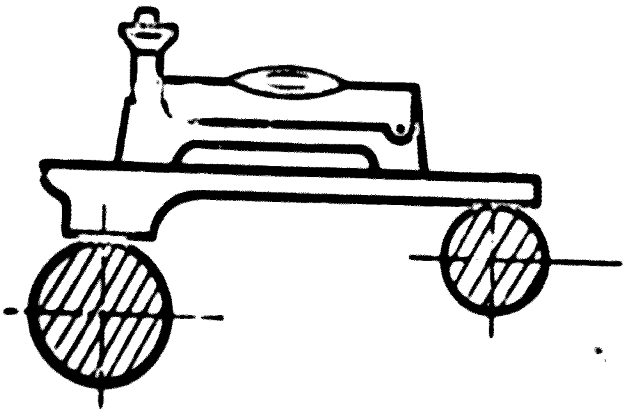

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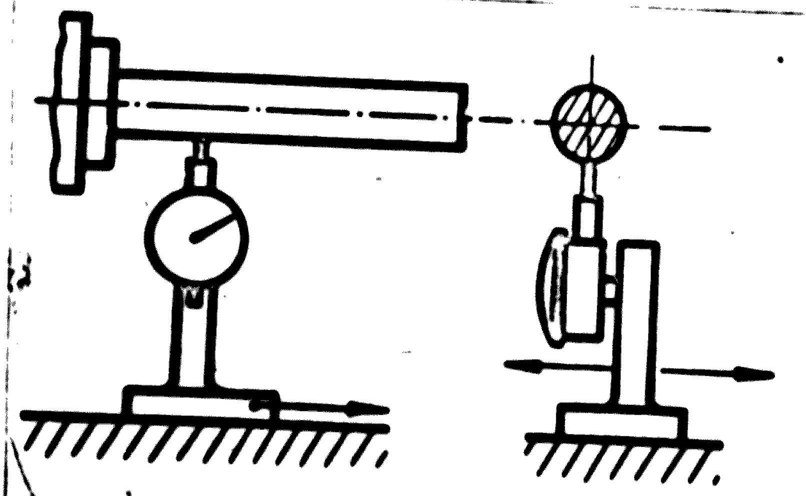

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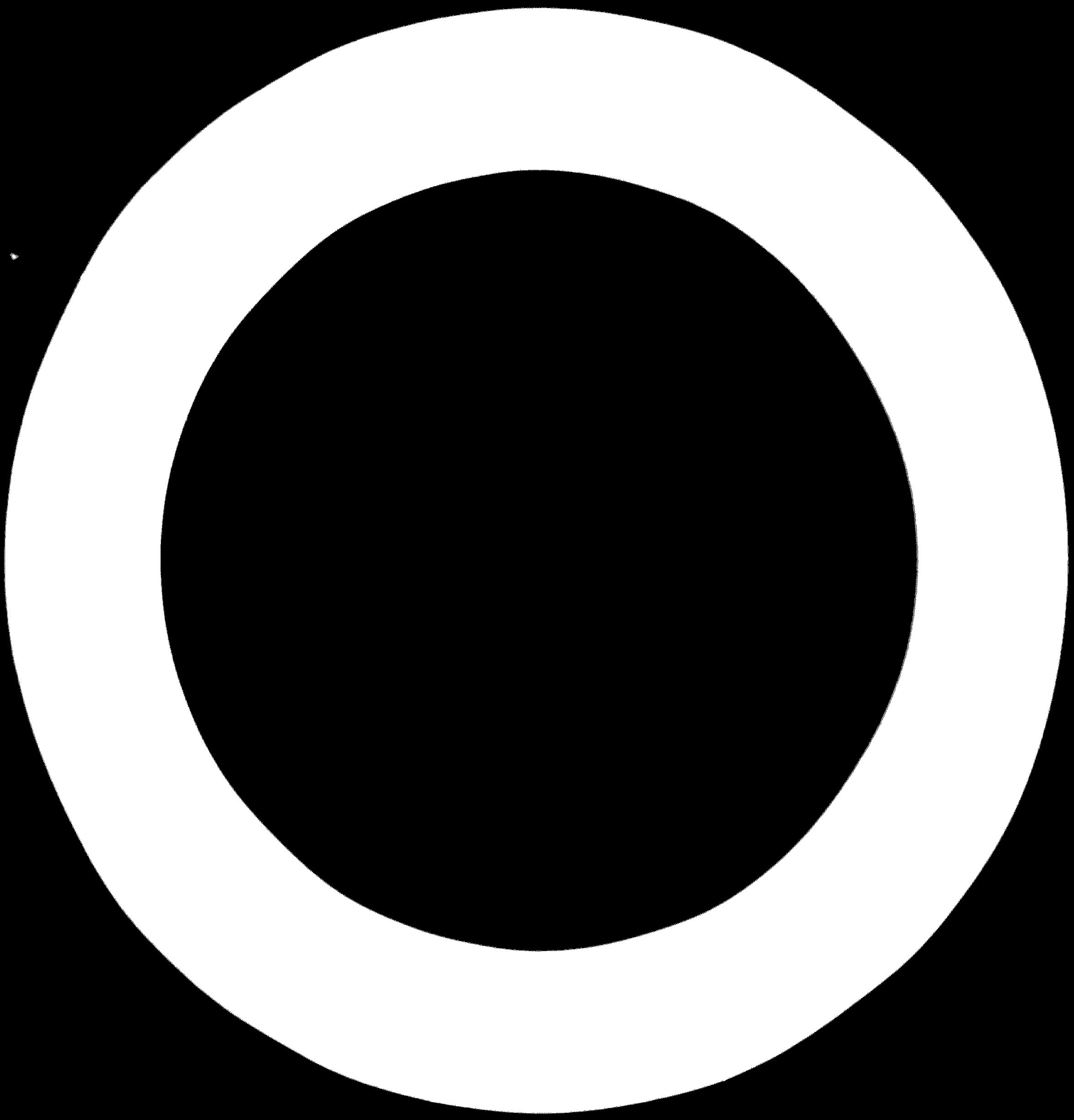

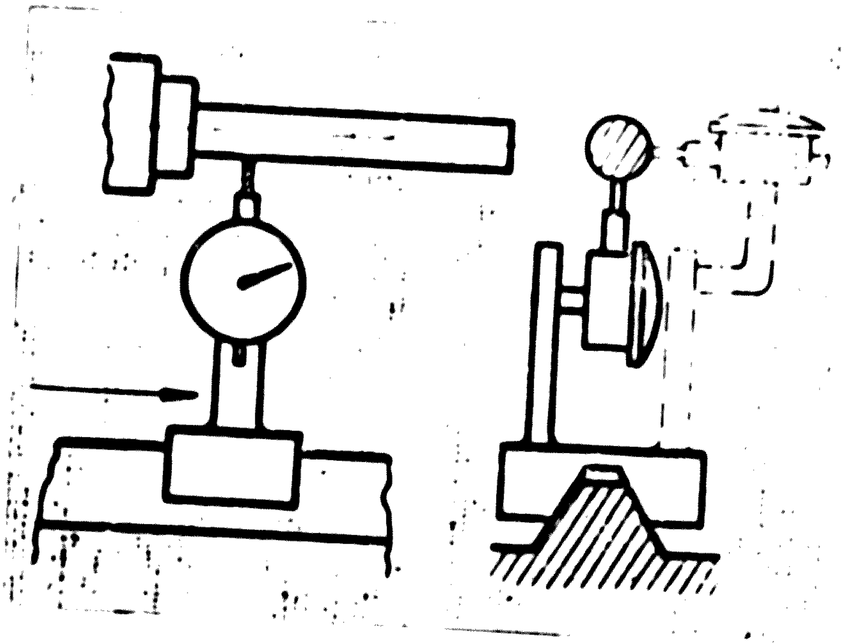

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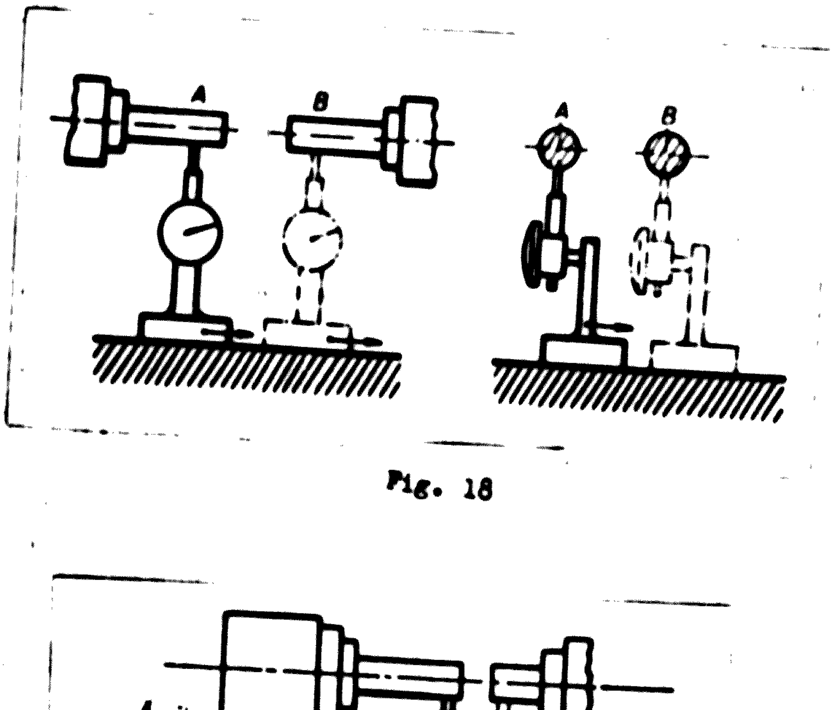

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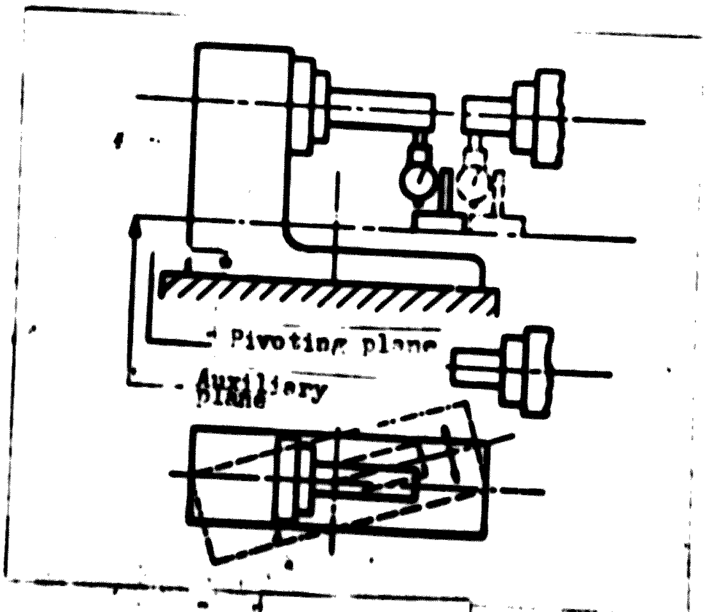

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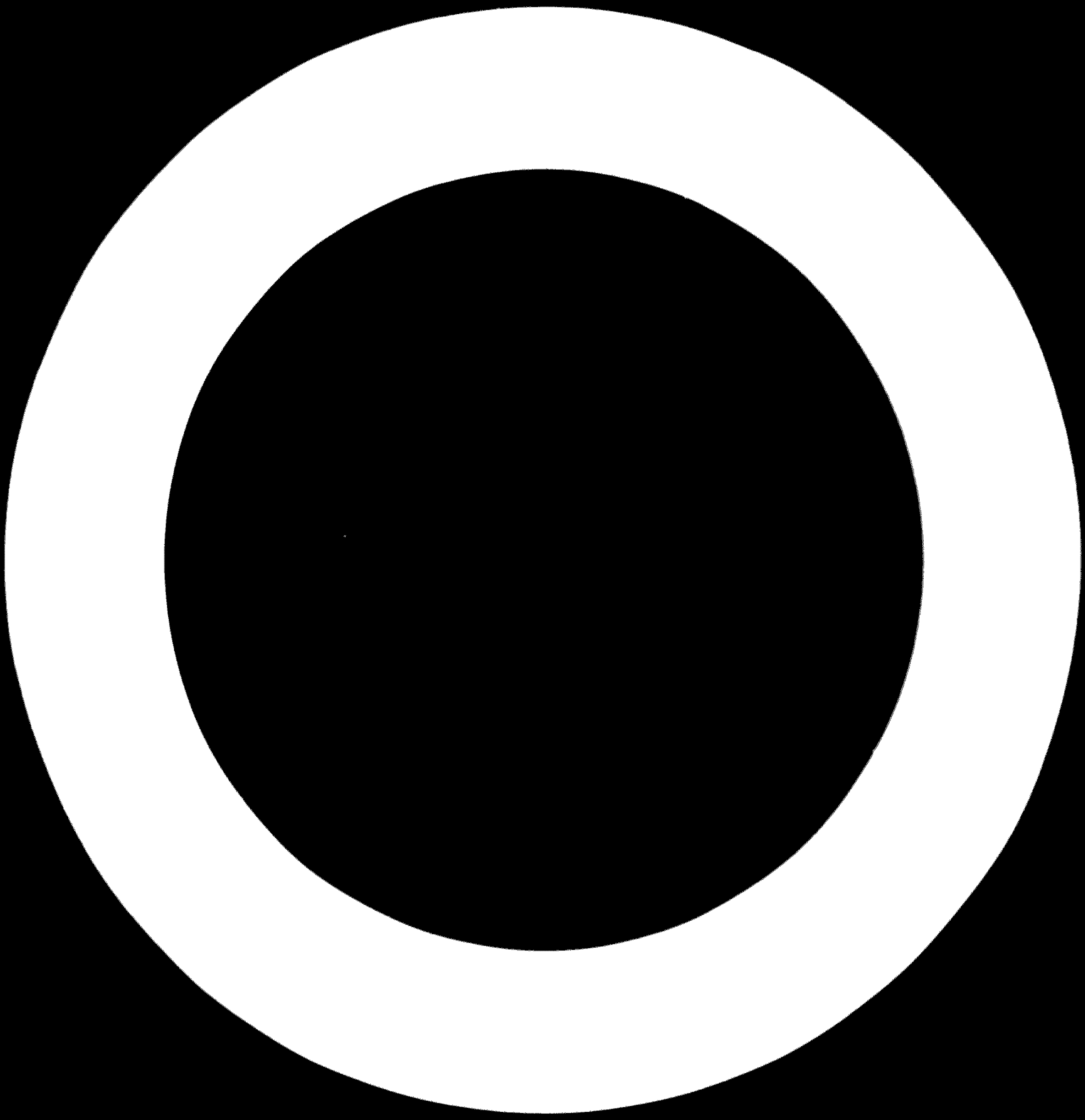

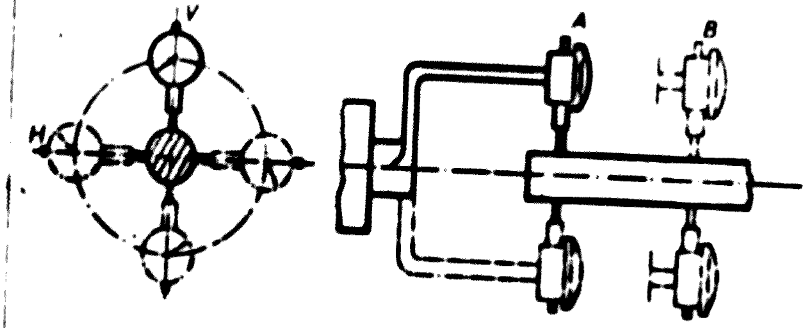

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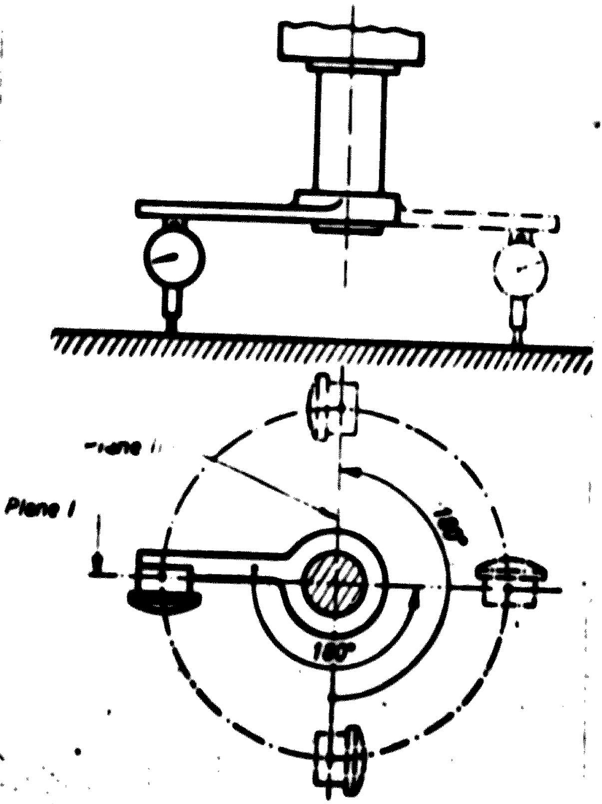

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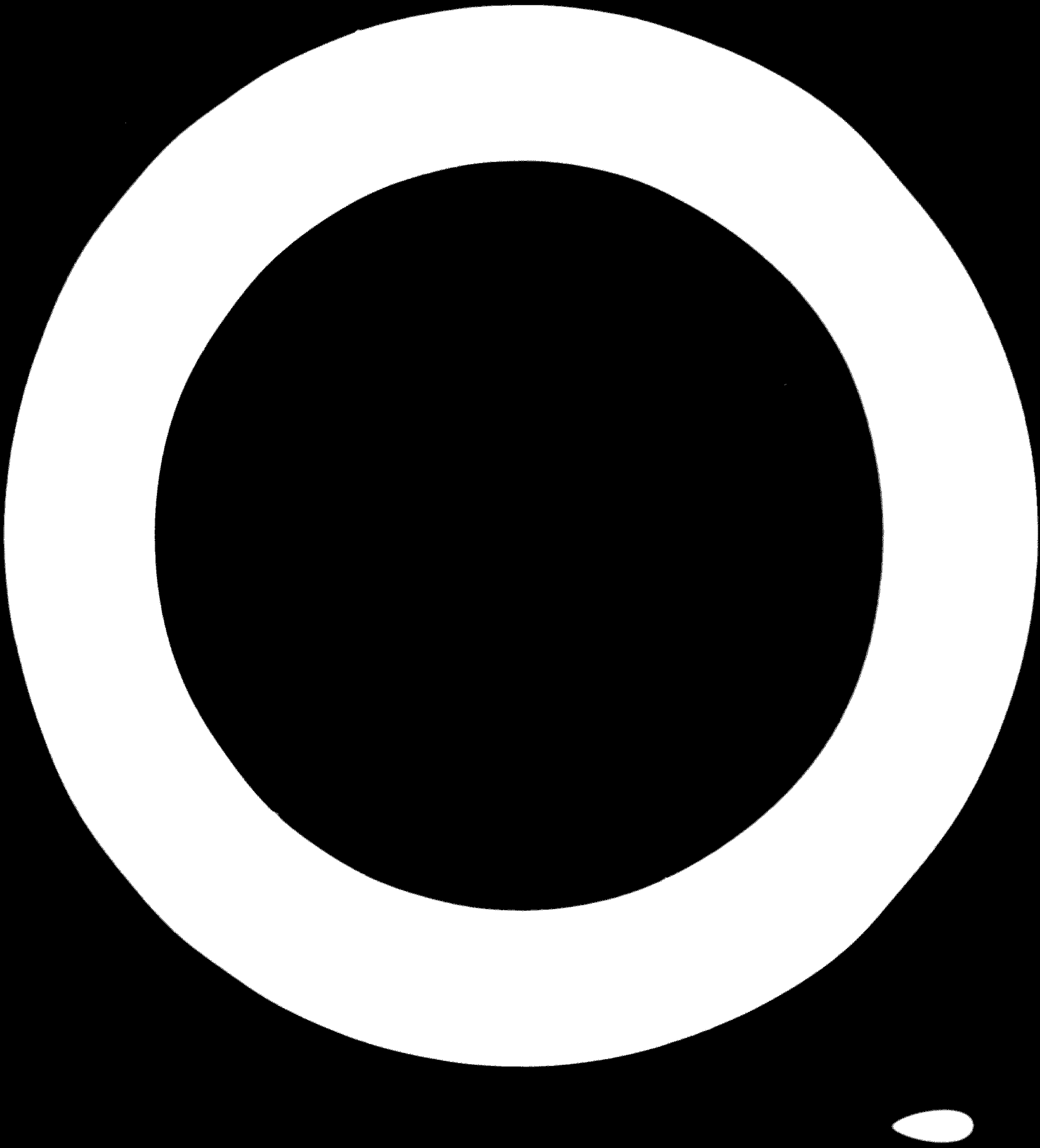

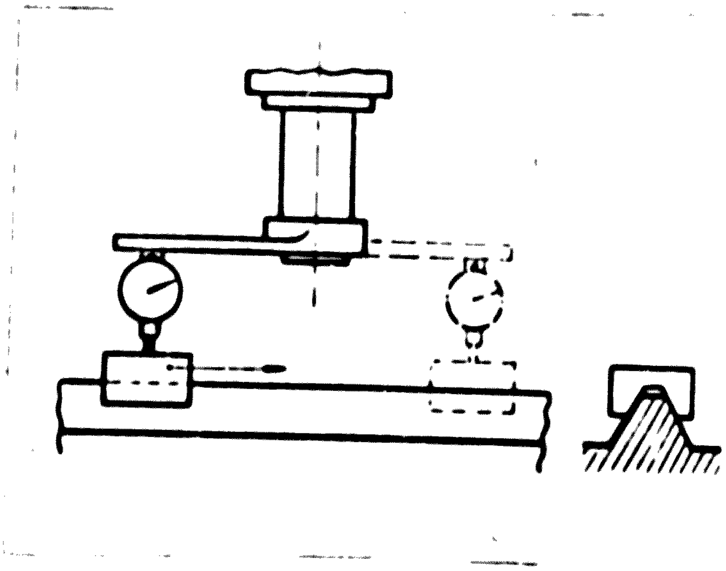

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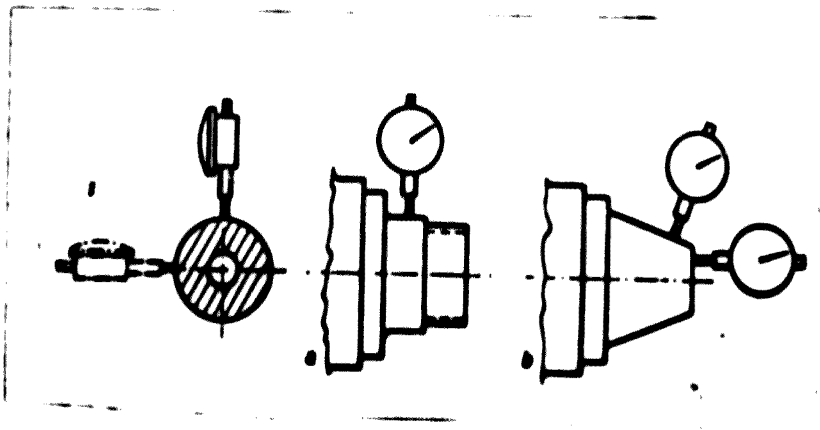

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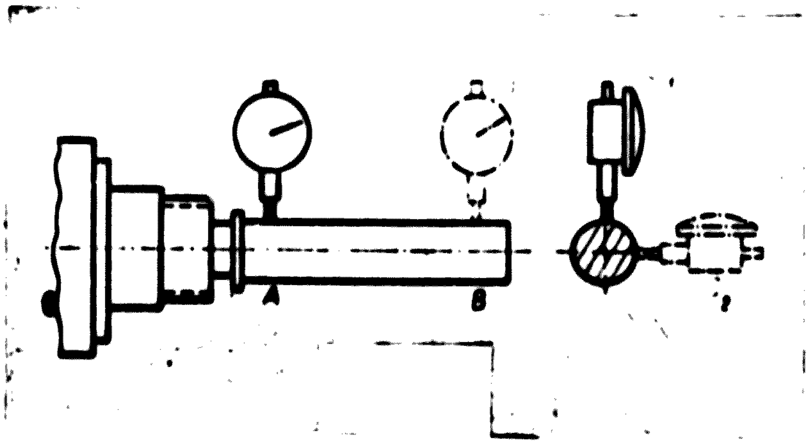

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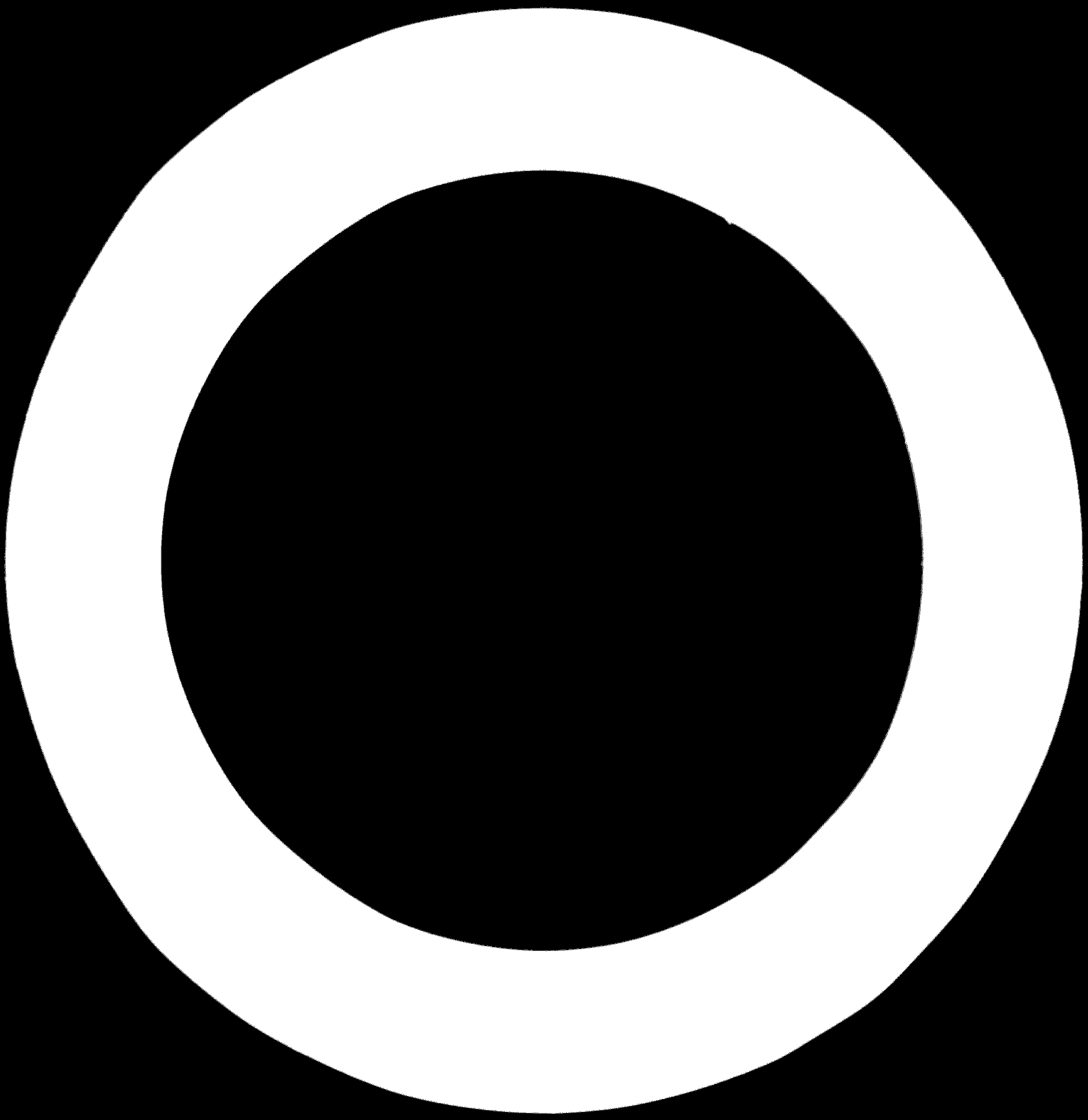

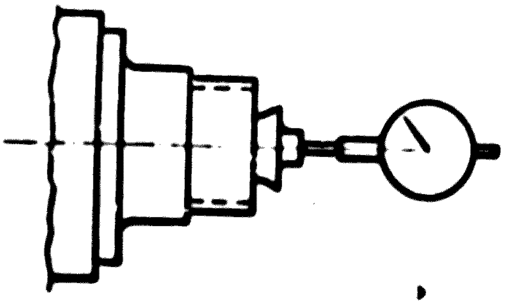

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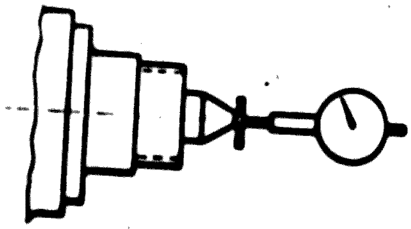

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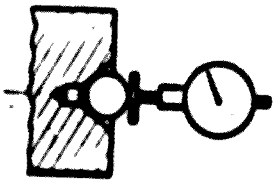

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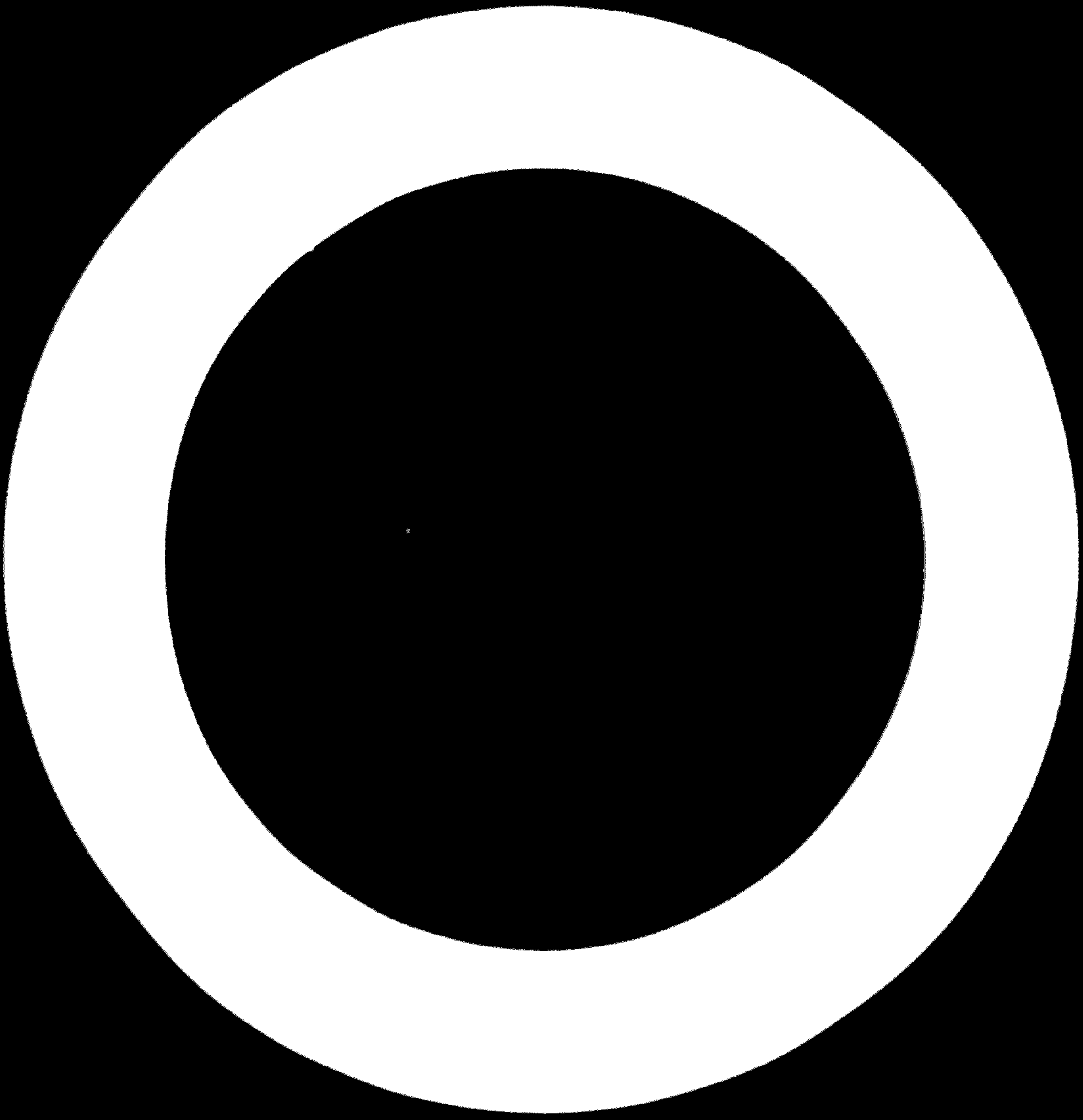


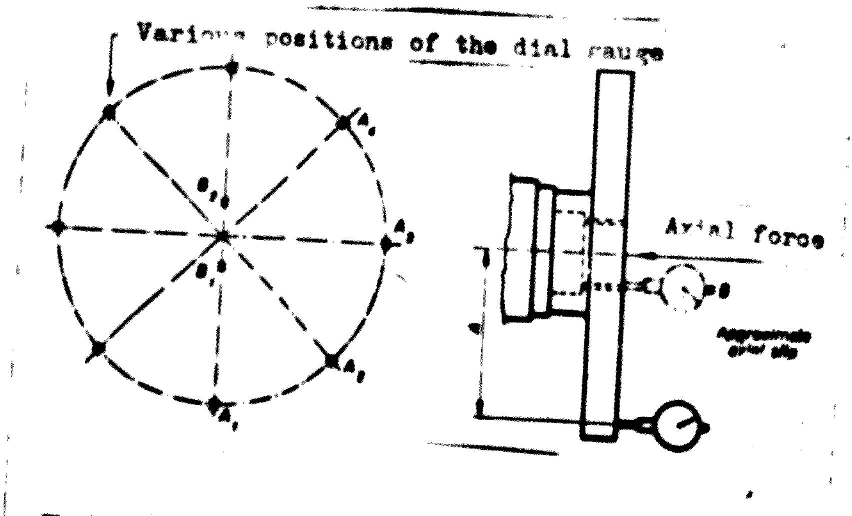
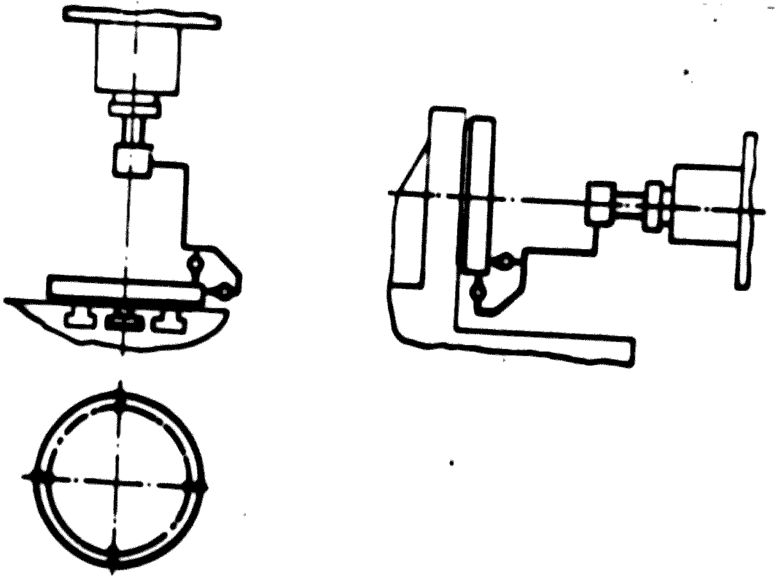

Various positions of the dial gauge
Axial force
Approximate axial slip
a

Fig. 26



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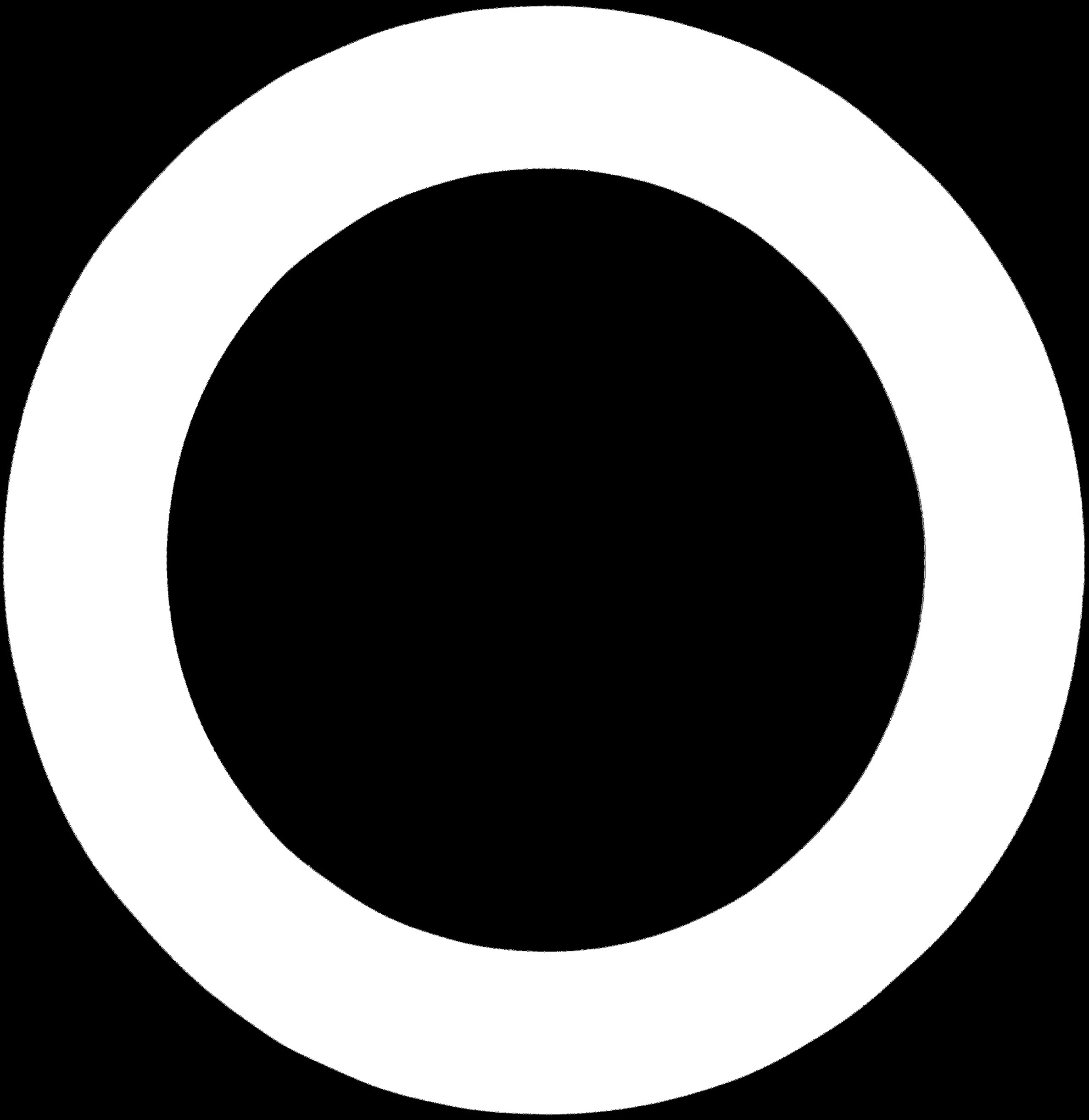

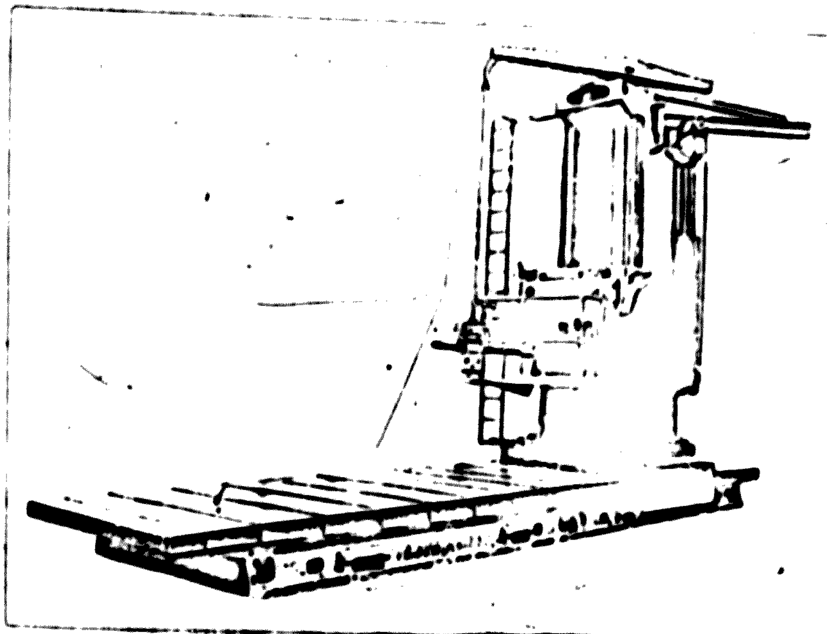

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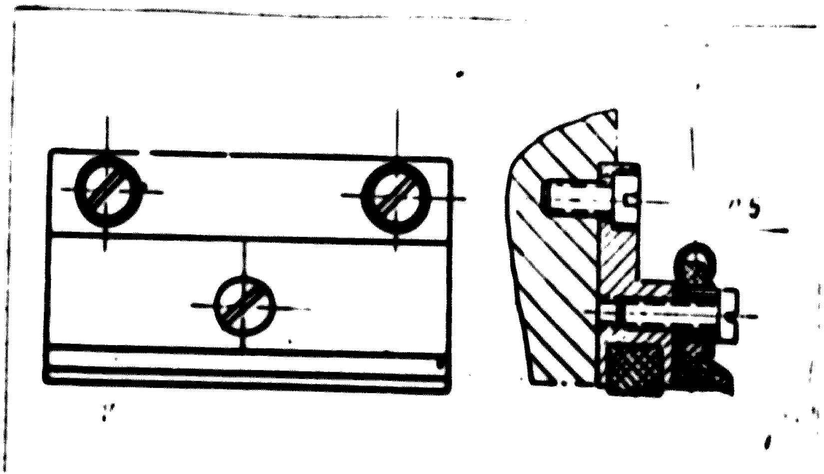

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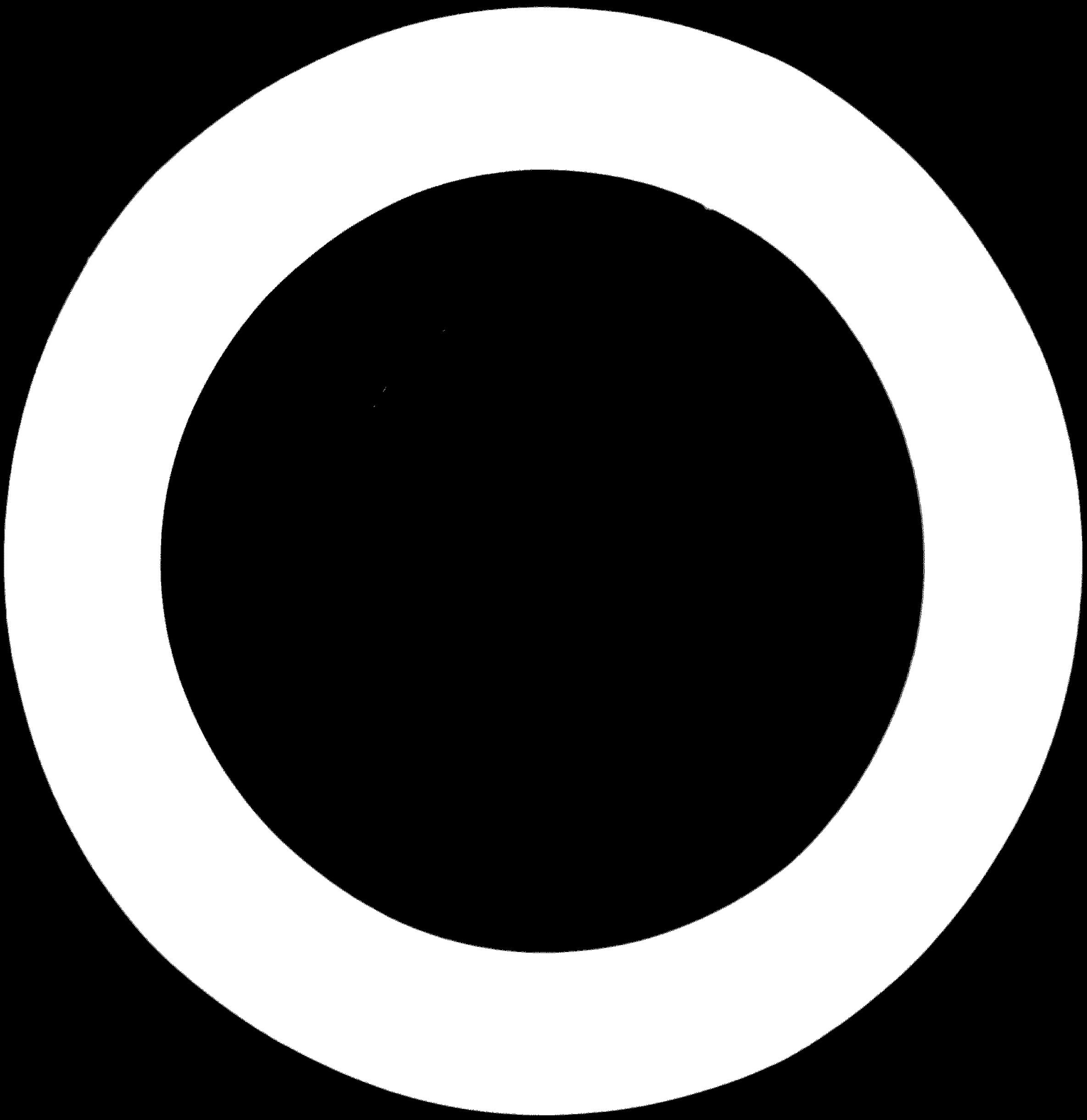

Practical Directions

1. The purpose of these directions

The process of industrialization is now taking place to a greater or lesser extent in almost all countries of the world, and one of the most striking manifestations of this process is the widespread establishment of machinery construction and metalworking undertakings, together with modern plants for the overhaul of equipment and the production of spare parts.

Although the production of machine tools is still restricted to a limited, albeit constantly growing, number of countries, the demand for machine tools has become world-wide, and many countries have to import such machines on an increasing scale.

It is very important for technicians in such countries to be in a position to make an expert evaluation of the quality of imported machine tools and to compare from test results the quality of similar tools produced by different factories.

The purpose of these practical directions is to enable such technicians to arrange for the examination of machine tools on receipt in such a way as to secure an objective evaluation of their quality, both by carrying out appropriate tests and by evaluating their design and quality of manufacture from the point of view of the machines' ability to afford the requisite precision in production work and to retain their initial qualities over a long period of use.

We have deliberately avoided recommending excessively complicated tests and, in particular, tests calling for the use of complicated measuring instruments which are usually available in the factories where the machine tools are produced but are not available to the consumers of the tools.

In a number of cases it is proposed that evaluation should be carried out without any measuring at all, since testing with complicated apparatus would be feasible only in a special laboratory staffed by highly qualified technicians.

The programme of tests specified in these directions is not obligatory in all cases, and in practice it is necessary to decide in each separate case which tests should be applied.

The individual tests described in these directions are applicable mainly to widely-used machine tools designed for the machining of various parts made of steel, cast iron, or non-ferrous alloys and for effecting various different machining operations. In the case of specialized machine tools, and particularly in the case of highly specialized tools, testing is effected by carrying out the operations for which the machine tool is designed, thus enabling an evaluation to be made of its productivity and precision in the very conditions in which it will be used in industry.

2. General requirements regarding the conditions in which acceptance tests are carried out

2.1 Setting up machine tools for testing, and protecting them from vibrations induced by outside sources

The machine tool must be fixed on a solid base or on a concrete slab in the workshop.

After the machine tool has been set up on its base or on a concrete slab, it must be carefully checked to see that it is level. The degree of accuracy with which the levelness of the machine tool must be checked is specified in the precision standards accompanying the tool and also in national standards on the precision of machine tools.

The high-precision levels used to check machine tools must have a scale division of 0.02 mm per 1,000 mm or, in the case of high-precision machine tools, 0.01 mm per 1,000 mm (0.0002 inch per 10 inches or 0.0001 inch per 10 inches, respectively).

When checking the level of machine tools, all movable parts of the tool must be in their mid positions.

To test the levelness of a machine tool a spirit level is placed on the carriage, the table or any other part of the machine tool which can be moved along the longitudinal guides of the machine frame (Fig. 1). When the level is moved along the direction of movement, the movement of the bubble in the level indicates the rectilinearity in the vertical plane of movement along the guides.

If the level is placed perpendicularly to the direction of movement, the degree of truth of the guides can be evaluated.

When the movable table or other part of the machine tool has a very short travel, or when there is no provision for such movement at all, the levelness of the machine can be verified by calculating the horizontality of the table or other part of the machine tool and eliminating as far as possible any deviation from perfect horizontality. Except in cases where the machine tool is on a three-point mounting, the levelling operation involves a certain amount of elastic deformation of its frame. The frame must therefore be brought into the position it occupied when the machine tool was checked for precision at the factory where it was produced.

Adjustment of the levelness of the machine tool is effected by adjusting the height of the individual supports on which the machine is fixed: that is to say, the supporting screws (jacks), adjustable wedge shoes, steel wedges or other devices (Fig. 2).

When a medium-sized machine tool has been levelled by the adjustment of steel wedges, it is advisable to pour cement grout under the sole of the machine frame so that the adjustment will be retained for a long period and the tool's stability and resistance to vibration will be enhanced.

It is not essential to fasten machine tools of this category to the base with anchor bolts unless the machine is to carry out particularly heavy work, such as machining unbalanced workpieces, carrying out intermittent cutting, and so forth, or unless fastening with anchor bolts is essential for reasons of safety, as for example in the case of radial drilling machines.

When setting up long, heavy machine tools on their bases it is necessary to use regularly spaced supports such as screw-jacks or wedge shoes arranged alongside or coaxially with the anchor bolts cemented into the base. This makes it possible, during the operation of the machine, periodically to readjust its level which may be altered by settling of the base, and thus avoid distortion of machine tools with fast-moving reciprocating tables.

In order to facilitate the mounting of medium-sized machine tools which often may need to be moved, and also in order to insulate them from vibration induced from outside sources, such machines may be mounted on resilient vibration-damping supports equipped with adjustable screw-jacks for restoring the levelness of the machine (Fig. 3). This method of mounting is particularly suitable in the case of machines mounted on upper floors of buildings, as it reduces the dynamic loads on the floor.

It must be borne in mind that mounting machine tools on vibration-insulating supports may lead to deterioration of the operation of the machine tool if there are internal sources of induced vibrations within the tool itself, such as unbalanced electric motors, pumps, spindles, excessively abrupt reverses of reciprocating tables, intermittent cutting with a strong tool bite, and so forth. It is not recommended that machine tools with relatively flexible frames which are designed to be complementary to the base, such as the frames of long lathes, planing machines and other machine tools, should be mounted on resilient vibration-insulating supports.

When high-precision machine tools such as jig-boring machines, thread grinding machines, etc. require special protection from the influence of outside sources of disturbance (for example when they are located near planing machines, forging hammers or heavy bridge cranes), it is recommended that they should be mounted on vibration-insulating bases consisting of reinforced concrete or concrete blocks set on springs (Fig. 4a) or resting on special rubber, composition or other pads (cushions) (Fig. 4b).

When bases are to be used for the temporary mounting of machine tools solely for testing purposes, it is as well to fit the bases with steel or iron beams with T-section slots to receive the fastening bolts (Fig. 5).

When selecting a method of mounting a machine tool for acceptance tests, the instructions of the machine-tool manufacturer should be taken as the main guide.

2.2 Maintenance of a constant temperature in the place of testing

For the common machine tools which form the basic equipment of machine shops, such as lathes, milling machines, drilling machines, boring machines, planing machines, grinding machines, gear cutting machines, etc., strict maintenance of a given temperature in the place of testing is not necessary, but it is essential that the temperature should not undergo sharp changes while the precision tests are being carried out - that is to say, from the time the levelness of the machine is adjusted until the end of the geometrical tests and the tests of the machine's precision in operation. During this time, the changes in temperature in the place of testing must not exceed 5°C.

During testing, the machine tool must be protected from the direct rays of the sun, from direct streams of hot or cold air from the heating and ventilation system, from draughts from open doors in winter, and so forth.

During the acceptance testing of high-precision machine tools such as jig-boring machines, thread grinding machines, high-precision grinding machines, gear grinding machines, etc., the test area must be kept at a given temperature. In most cases, the standard temperature of 20°C is adopted, but in certain cases, depending on climatic conditions, other temperatures such as 17°C in winter, 23°C in summer and so forth may be adopted.

In these latter cases, if the machine tool was tested for precision at its factory of origin at a temperature of 20°C, it may prove necessary to take into account the difference in the coefficients of linear expansion of the materials from which the workpiece (which may be of aluminium alloy, for example) and the parts of the machine tool are made, as such expansion determines the accuracy of positioning of, for example, the linear measuring mechanism of a co-ordinate boring machine. In the testing of high-precision machine tools, the permissible deviation from the standard temperature in the whole of the test area is subject to particularly strict requirements.

For most high-precision machine tools this deviation must not exceed ± 1.0°C, while for the highest-precision machines it must not exceed ± 0.5°C.

In order to maintain such constant temperatures, the test area must be provided with an automatic air conditioning system capable of satisfying these requirements.

The requirements regarding the temperature to be maintained in places for high-precision machine tools are usually stated by the manufacturers of the machines in the technical documentation accompanying them.

2.3 The condition of the machine tool before testing

Prior to the commencement of acceptance testing the machine tool, mounted on its base as specified in section 2.1, must be completely fitted with all its attachments and technical equipment. The lubrication and hydraulic systems of the machine tool must be filled up with oil of the appropriate type, as indicated in the documentation supplied by the manufacturers of the machine.

The machine tool must be completely cleaned of its anti-corrosion coating.

If any individual movable parts were fastened down to prevent them from moving during transport, they must be freed of their temporary fastenings or spacers, and before testing they must be moved by hand to make sure that there is no hindrance to their movement.

All the protective devices designed to ensure safe operation must be fitted to the machine tool.

2.4 Warming up the machine tool before precision testing

As a result of mechanical losses through friction, of oil throttling in the hydraulic system, of electrical losses in the motors and mechanisms built into the machine, and also as a result of the process of machining itself, heat is generated during the operation of a machine tool and there is unequal heating of its individual parts, which leads to their heat deformation and changes their mutual position and sometimes even their shape. Before testing the precision of the machine tool, therefore, it is necessary to warm up the machine by running it light so as to bring the temperature of its various parts up to the normal level attained during operation. However, not all geometrical tests require prior warming of the machine tool so there is no need to perform all of them immediately after the machine tool has been warmed up. It must be ascertained which tests require the machine tool to be warmed up immediately before they are effected. In lathes, temperature deformations due to the generation of heat in the spindle bearings exert a substantial influence on the position of the spindle axis relative to the frame guides along which the cross slide moves and to the axis of the tailstock spindle.

In turret lathes, warming up by light running affects the position of the axis of rotation of the spindle relative to the tool holders of the turret, the direction of longitudinal movement of the turret, and the longitudinal and transverse movement of the slides of the cutting head (the cross slide).

In vertical jig-boring machines, warming up the machine by light running leads to displacement, with respect to the table, of the axis of rotation of the spindle (horizontal displacement and divergence in a plane perpendicular to the longitudinal movement of the table).

In surface grinding machines heat distortion of the machine may lead to non-parallelism between the surface that is being ground and the surface of the table.

3. Verifying that the technical characteristics of a machine tool coincide with its rated data

It must be verified that all the technical characteristics of a machine tool: i.e., the travel of its various movable parts, the maximum dimensions of the workpiece which can be machined in it; the number of revolutions per minute of the spindle or the number of to-and-fro movements per minute of the working parts of the machine; the feed speed and the maximum screw cutting pitch, etc., coincide with the data on the technical characteristics of the machine tool provided by the manufacturer.

4. Checking the completeness of the technical equipment and normal fittings

When checking all the normal fittings against the packing list, one should also check the completeness of the entire set of technical equipment ordered for the operations specified when the machine tool was purchased. All this equipment must be checked when it has actually been installed on the machine tool and is ready to carry out its particular technical operation.

5. Testing of the machine tool when running light

5.1 Induced vibrations in the machine tool when running light

An important condition for ensuring that a machine tool can perform precision work is that when running light the parts of the machine tool which carry the cutting tool and the workpiece should be free of induced relative vibrations. The presence of such relative vibrations in the machine tool may lead to the appearance of unacceptable undulations in the machined surface or to imperfect circularity of that surface.

Measuring the amplitude of such relative vibrations during light running calls for the use of special instruments which the users of machine tools do not usually possess. They will therefore have to make do with a subjective evaluation "by touch" of the outwardly apparent vibration of individual parts of a machine tool such as the head and tail stocks, the electric motors, the pumps and so forth. Such an evaluation is mainly of use in comparing one machine tool with another. The final decision on the permissibility of the level of vibration observed in grinding machines during light running must be taken on the basis of the results of the finishing grinding of test pieces (see below, section 7.2).

5.2 The smoothness of reverse of reciprocating parts of the machine tool

When a machine tool incorporates fast-moving reciprocating parts (such as the tables of surface grinding machines, internal grinders and cylinder- and cone-grinding machines) whose speed is measured in tens of metres per minute, excessively abrupt reverses may set up transient vibrations in certain parts of the machine at the moment of reversal, and in particular, relative vibrations in the grinding spindle and in the parts of the machine carrying the workpiece (the table and the heads between which the workpiece is held).

When machine tools are received by the purchaser, the smoothness of reverse can be evaluated only subjectively "by touch", and this is mainly of use only for making a comparative evaluation of machines manufactured by different factories. A final evaluation can be made on the basis of the results of grinding test pieces with the machine adjusted so that there is the minimum permissible amount of free movement at the beginning and end of each stroke or so that the grinding disc does not break contact with the workpiece. This last condition is important, because the induced vibrations set up at the time of reversal die out relatively quickly.

If, for example, when grinding a shaft on a cylinder-and-cone grinding machine, the table reverse is not sufficiently smooth, undulations may appear at the ends of the shaft if the induced vibrations set up at the time of reversal have not died out before grinding is begun.

When grinding without the grinding disc leaving the workpiece - as, for example, when grinding up to a bead or rib - there is an even greater danger that traces of vibration will appear in the ground surface at the end of the stroke.

5.3 Noise of the machine tool

The noise of the machine tool must be evaluated from the point of view of its harmful effect on the operator of the machine and also on those working nearby.

When it is necessary to measure the noise level of a machine tool, a noise gauge must be used.

It is recommended that one of the following noise gauges be used:

1. Sound level meter, type 1400 C or type 1402 C. Dawe Instruments Ltd., Great Britain.
2. Precision sound level meter. Type 2203. Brüel & Kjaer (Denmark).
3. Kleinlautstärkemesser LSM 2. VEB Werke für Fernmeldewesen, Berlin (German Democratic Republic).

Sound level meters used for measuring the noise level of machine tools must comply with the standards of the International Electrotechnical Commission (IEC).

Workshops in which the noise-level testing of machine tools is carried out must comply with the following requirements:

1. The level of background noise from the operation of other equipment installed in the same or neighbouring workshops must be at least ten decibels lower than that of the total noise of the machine tool under test and the background noise. If the difference is less than ten decibels, the influence of the background noise must be taken into account by deducting from the total noise level the correction figure given in the table below.

Difference between total noise level of machine tool plus background noise and level of background noise	Correction ΔL (in decibels)
from 9 - 6 decibels	1
from 5 - 4 decibels	2

2. In order to avoid excessive distortions in the measurement of the noise level of a machine tool as a result of the reflection of sound waves from the walls and ceiling of the workshop, the machine tool must be situated not less than two metres from the walls and the height of the ceiling must be not less than two metres above the highest part of the machine tool.

Measurement of the noise level of the machine tool is carried out at the workplace at a height of 1.5 metres above floor level and at a horizontal distance of one metre from the outline of the machine tool. Noise-level testing is normally carried out when the machine is running light, but in special cases, when necessary for technical reasons, it can be carried out when the machine is working under load.

The noise level of a machine tool, when recorded in this manner, must not exceed 77 to 82 decibels (on scale A of the sound level meter).

5.4 Power losses in the main drive of the machine tool

Power losses somewhat limit the productivity of a machine tool, since they lower its effective power, that is to say, the power directly available for machining purposes.

The level of power losses or, to be more exact, the mechanical efficiency of a machine tool, is an index to the degree of perfection of the main drive mechanism.

The coefficient of mechanical efficiency η is calculated through the following approximate formula:

$$\eta = 100 - \frac{N_0}{N_1} \cdot 100 - (P_1 + a.P_2 + b.P_3 + c.P_4)$$

where: N_0 is the amount of electric power consumed by the main drive of the machine tool during light running, in kilowatts, after subtraction of internal losses in the electric motor.

N_1 is the rated power of the electric motor in kilowatts (at the shaft of the motor);

P_1 is the louses in the belt drive, in per cent; for vee-belt drives $P_1 = 3\%$, while for flat belt drives $P_1 = 2\%$;

P_2 is the losses in the gear drive, in per cent; $P_2 = 1\%$;

P_3 is the losses in rolling bearings, in per cent; $P_3 = 0.25\%$;

P_4 is the losses in sliding bearings, in per cent; $P_4 = 2\%$;

a, b and c are the numbers of gear drives, rotary bearings and sliding bearings, respectively.

The mechanical efficiency of the main drive of a general purpose machine tool fitted with a gear box is usually $\eta = 0.7 - 0.8$, while that of fast-running machine tools operating at maximum speed is $= 0.55 - 0.60$.

5.5 Testing the controls of the machine tool

Testing the correct functioning of the manual control systems consists basically in checking the smooth engagement and disengagement of the friction clutches of the main drive, the speed changes of the gear box, the transmission box speed changes, and the satisfactory operation of the various other manually controlled mechanisms. Particular attention should be paid to the amount of force which it is necessary to apply to the levers and control wheels and, if necessary, this force should be measured with a simple dynamometer. Checks should be made to verify the correct functioning of the interlocking devices which prevent the simultaneous engagement of incompatible machine movements.

When checking the correct changing of speeds in the gear box, particular attention should be paid to the relative positions of the gear wheels once they have been engaged. After engagement, the gear wheels should mesh across the whole width of their teeth.

On machine tools provided with apparatus for the automatic disengagement of the feed mechanism or of adjustable traversing mechanisms, not only must the smooth operation of the disengagement mechanism be tested a number of times, but the accuracy of the final position of the part of the machine moved by the mechanisms in question must be tested after automatic disengagement of the feed or traversing movement at various running speeds. Such tests must be carried out a number of times and their results must be evaluated in the light of any wandering of the final position of the part of the machine in question.

On machine tools with an automatic working cycle, the correct functioning of the cycle control system must be checked.

5.6 Checking the heating of individual parts of the machine tool under light running

The spindle bearings, the electric motors, the hydraulic pumps and the hydraulic cylinders must be tested after the machine tool has been run light for three hours.

Excessive heating of individual parts of the machine tool is not permissible, firstly because excessive heating of such parts as rotary and sliding bearings, the windings of electric motors and so forth affect the capacity of the machine tool to perform its work properly, and secondly because excessive heating may distort parts of the machine and affect the precision of machining.

Temperature measurements are carried out by fixing thermocouples on the outside walls of the spindle blocks at the point where the bearings are located, on the walls of hydraulic cylinders, and so forth.

If the body of the spindle block has a vertical blind cavity which communicates directly with the spindle bearing and into which oil may be poured, then the bearing temperature may be measured by submerging the end of a mercury thermometer in the oil.

The operation of the friction clutch of the main drive should be tested by repeatedly engaging it and disengaging it. While this is being done, the clutch should not heat up to more than 10 °C above the ambient air temperature of the workshop. The frequency of engaging and disengaging the clutch should correspond to the frequency of cluth operation when machining small parts.

6. Testing the machine tool under load

6.1 Testing at full power

The operation of a machine tool at full power is tested by machining appropriate workpieces most representative of the type of work to be performed on the machine tool under test in normal operation.

The cutting rate should be selected to make full use (taking into account transmission losses) of the rated power of the electric motor of the main drive, as checked with a watt meter. During testing, particular attention should be paid to verifying the normal functioning of the main drive mechanism of the machine tool. In particular, it should be verified that the main drive friction clutch is properly adjusted and operates without slipping and overheating.

The tests should be carried out both at one of the intermediate speeds and at the maximum speed of rotation of the spindle.

6.2 Testing at maximum cutting capacity

The purpose of testing the operation of a machine tool at maximum cutting capacity is primarily to check the functioning of the feed mechanism (on machine tools where feeding takes place simultaneously with machining).

This testing is carried out at one of the lowest available spindle speeds (within the lowest quarter of the range of adjustment of spindle speed).

The feed setting is determined from formulae or from tables of recommended cutting rates, and should be such as to test the maximum permissible rated technical characteristics of the machine tool.

During testing, particular attention should be paid to the operation of the feed mechanism, especially the proper functioning of the protective device designed to limit the torque transmitted by the feed mechanism.

6.3 Vibration resistance of the machine tool during machining

Dangerous vibrations during machining are usually of an auto-oscillating nature, and they can be generated as a result of the properties of the closed dynamic system (which consists, at its simplest, of an elastic system comprising machine tool - attachments - tool - workpiece), the machining process and other factors.

Resistance to the generation of vibration during machining is one of the most important indices of the quality of a machine tool.

When a certain limit cutting rate is attained, the system referred to above ceases to be stable and sharply marked traces of vibrations appear on the machined surface in the form of undulations ("chatter marks"). When such vibration arises, the machining process must be suspended, and a different cutting rate must be adopted. The limit cutting rate at which vibration sets in can considerably restrict the productivity of a machine tool by preventing the full utilisation of the machining capacity which the strength and rigidity of the machine and the effective power of the drive would otherwise allow.

When machine tools are being tested for vibration resistance in the conditions of a specialized laboratory, tests are made to determine the limits of stability, that is to say, the dependence - for a given type of machining, sise of workpiece, tool shape and rate of feed - between the maximum depth of cut and the speed of the main direction of cutting.

Recently, vibration resistance tests have been carried out without actual machining by using special instruments which enable the dynamic characteristics of a machine tool to be determined by the artificial generation of vibration by means of a vibrator.

In the conditions in which machine tools are tested by the consumer, however, such tests are too complicated and recourse must therefore be had to simpler methods.

These simpler tests consist basically in the determination of the maximum depth of cutting at optimum machining speed of a test piece of given size, using a given type of tool and a given rate of feed.

When testing lathes, the test piece used takes the form of a cylinder with a conical tail which is placed in the conical socket of the spindle. When testing lathes with a maximum machining diameter of D = 320 mm (height of centres: 160 mm), the diameter of the cylindrical part of the test piece is d = 50 - 60 mm and the length of the cylindrical part is l = 250 mm.

For lathes where D = 400 mm (height of centres: 200 mm), the corresponding dimensions are d = 60 - 70 mm and l = 300 mm.

When testing column-and-knee milling machines (both vertical and horizontal), test pieces consisting of rectangular pieces of steel are used.

For machines with a table size of 250 x 1000 mm the dimensions of these test pieces are length L = 200 - 250 mm, height H = 110 - 125 mm, and breadth B = 75 - 90 mm.

For machine tools with a table size of 320 x 1250 mm, the dimensions of the test pieces are: L = 250 - 320 mm, H = 140 - 160 mm and B = 95 - 110 mm.

The tools used should be face cutters with hard alloy blades and cylinder cutters made from high speed steel.

As there are no generally accepted standards for the vibration resistance of machine tools, the vibration resistance testing of machine tools serves mainly for a comparative evaluation of the quality of similar machine tools made by different manufacturers.

By comparing the limit cutting rate at which vibration sets in with the cutting rate corresponding to the maximum effective power of the machine tool and its sturdiness of construction, it is possible to evaluate the degree of vibration resistance of the machine tool when machining.

7. Precision testing

7.1 General considerations

In accordance with Recommendation ISO/R.230, "Machine tool test code" (First edition, 1961), the precision testing of machine tools comprises operational tests of the machine tool and geometrical tests.

Methods for the precision testing of machine tools, together with details of the permissible deviations from the set standards, are specified for machine tools of various types in national machine tool precision standards and in the precision standards of the machine tool manufacturing firms themselves.

Precision standards for machine tools of several types are given in Annex 1.

The official report on the tests performed in accordance with established precision standards accompanies each new machine tool when it is delivered.

7.2 Operational testing

The precision standards for machine tools provide for operational testing, which consists of the finishing machining of test pieces of given dimensions.

The size and shape of the test pieces to be used in such operational tests are specified in the precision standards for the various types of machine tools.

The dimensions of the test pieces are selected so that one test piece can be used for the testing of the largest possible number of machine tools. In order to reduce tool wear in the machining of a single test piece, the surface to be machined is not continuous, but is in the form of narrow rings. When machining test pieces between centres, the centre holes of the test piece must be accurately ground. Machined test pieces must be checked for accuracy of shape and for accuracy of the positions of the surfaces machined during testing with respect to the initial surfaces of the test pieces.

Thus, for example, when machining rotating bodies during the testing of lathes, cylinder-and-cone grinding machines, internal grinding machines, boring machines and other types of machine tools, checks must be made of the shape of the cross-section, the cylindricity of the machined surface and the perpendicularity of the axis of the cylindrical surface to the end-face of the test piece.

When machining flat test pieces in the testing of milling machines, surface grinding machines, planing machines and similar machine tools, tests are made of the flatness of the machined surface and the parallelness or perpendicularity of this surface to the intitial surface.

When testing boring machines, the main types of machining operations characteristic of these machine tools, such as the boring of holes, the milling of flat surfaces, the machining of flat end surfaces by radial feeding of the cutting tool and the rounding-off of flanges with the cutting tool held in the faceplate, are carried out on a single test piece.

7.3 Geometrical precision tests

The geometrical precision testing of machine tools consists of the following:

(a) Testing the accuracy of the geometrical form of these surfaces of the machine tool on which the workpiece, the accessories and the tool are mounted such as the flatness of the tables of milling machines, planing machines, surface grinding and other machines, the flatness of the faceplates of lathes, facing lathes and so on, and the accuracy of the form of the conical surfaces of spindles, whether they are external (as in the case of the spindles of grinding machines) or internal (as in the case of the spindles of lathes, milling machines, drilling machines, boring machines and other machine tools).

(b) Testing the accuracy of the trajectory of movement of the operating parts of the machine tool which carry the workpiece and tool such as, for example, the rectilinearity of movement of the tables of milling machines, planing machines and surface grinding machines or of the carriages of lathes, the spindle heads of gear cutting machines and so on; the accuracy of rotation of spindles carrying the workpiece or tool; and the accuracy of rotation of the circular tables of vertical boring and turning machines, surface grinding machines, gear cutting machines and other machine tools.

(c) Testing the accuracy of the relative paths of the operating parts of machine tools carrying the work piece and the tool such as, for example, the parallelism with the spindle rotation axis of the longitudinal movement of the carriage of a lathe or the table of a boring machine, the parallelism of the vertical movement of the spindle head of a gear cutting machine with the axis of rotation of the table, and so forth.

(d) The accuracy of the relative paths of the operating parts of a machine tool which carry the workpiece or tool, with respect to the base surfaces for the mounting of the workpiece or tool such as, for example, the coaxiality with the plane of the table of the conical socket or external surface (conical or cylindrical) of the spindle, or the perpendicularity to the table of the axis of rotation of the spindle of a drilling machine; the parallelism of the direction of movement of the table of a milling machine, a planing machine or a surface grinding machine to the plane of the table; and so forth.

(e) The accuracy of the relation between the speeds of interdependent movement of operating parts of a machine tool which carry the workpiece and the tool such as, for example the relation between the speed of rotation of the spindle and the speed of linear movement of the carriage of a screw cutting lathe, the relation between the speed of rotation of the workpiece spindle and the speed of linear movement of the table of a thread grinding machine, or the relation between the speed of rotation of the milling spindle and the speed of rotation of the table of a gear cutting machine (this last speed ratio cannot be checked without special instruments, and evaluation must therefore be based on the results of the test machining of gear wheels on the machine tool).

(f) The accuracy of the unitary division (indexing) when the machine tool turns to a given angle, or the linear movement of a part of the machine tool to a given position (positioning) such as, for example, the accuracy of unitary division of the workpiece (the gear wheel) on a gear cutting machine, the accuracy of the co-ordinate displacements of the table of a jig-boring machine, and so on.

Geometrical measurements of accuracy are carried out at given positions (usually mid positions) of the parts of the machine tool, since in some cases, when parts are moved to other (e.g. extreme) positions, the resultant change in the position of the centre of gravity causes elastic deformations which disturb the rectilinearity of the horizontal displacement in the vertical plane, and so forth. For example, when testing the geometrical accuracy of a column-and-knee milling machine, a horizontal boring machine, or a jig-boring machine with cross tables, unacceptable tilting of the table to one side or another may be observed when the table is moved to an extreme position, because of inadequate rigidity of the table slides and other elements.

7.4 Elements of geometrical tests of machines and precision tests of machined test pieces

7.4.1 Types of geometrical tests

All the geometrical tests of machine tools, and the tests of the workpieces machined in order to test the precision of the machine tool in operation, consist of the following elements:

(1) Tests of rectilinearity of lines, parts or movement trajectories;
(2) Tests of flatness;
(3) Tests of the parallelism of lines, planes, or movement trajectories;
(4) Tests of equidistance (equal height) and coaxiality;
(5) Tests of the perpendicularity of straight lines, planes, or movement trajectories;
(6) Tests of accuracy of rotation (radial wobble), periodic axial displacement and wobbling of end faces;
(7) Tests of accuracy of division;
(8) Tests of the accuracy of displacement to given co-ordinates.

The methods and conditions for carrying out the first seven of these basic tests are described in detail in ISO Recommendation R.230, "Machine tool test code", first edition, 1961.

The methods for testing the accuracy of (rectilinear) displacements to given co-ordinates are described in the precision standards supplied with jig-boring and other machine tools.

7.4.2 Testing rectilinearity

The rectilinearity of lines and guides is tested with the aid of test straight edges, precision levels and, in the case of lengths exceeding 1600 mm (63 inches), with the aid of an auto-collimator or a microscope and taut string. Levels are used only to detect deviation in the vertical plane, while a taut string is used only in the horizontal plane.

When testing rectilinearity with the aid of a test straight edge (Fig. 6), the straight edge must be placed so that its ends are an equal distance from the surface or guide that is to be checked. A pedestal gauge whose sensing tip slides along the surface of the straight edge is then moved along the surface or guide (Fig. 7).

The whole length to be checked is divided into a number of sections, the reading of the gauge at the end of each section is noted, and a graph of the deviations from rectilinearity is then constructed (Fig. 8). The degree of inaccuracy is calculated from the deviations from the straight line joining the points corresponding to the beginning and end of the section that is being checked.

When verifying rectilinearity with a level, the whole length is likewise divided into equal sections - 100 to 500 mm in length - and a graph of deviations of level is constructed from the successive readings of the level gauge for each section (Fig. 9).

After the deviation of level of the sections has been checked first from left to right and then from right to left, the inclination of each section is taken as the arithmetic mean of both readings. After the points corresponding to the beginning and end of the length to be checked have been connected with a straight line, the deviations from rectilinearity are determined from the distanc along a vertical to this straight line to the corresponding point on the graph.

Optical instruments are rarely used for checking rectilinearity in acceptanc tests performed by consumers of machine tools, as such instruments are not usually available in these circumstances.

When checking the rectilinearity of movement of a movable element of the machine tool, the foot of a pedestal gauge is placed on the movable element and the sensing tip of the gauge slides along a fixed test straight edge. When rectilinearity is to be checked over a substantial length, a taut string can be used to determine deviations in the horizontal plane.

When testing the rectilinearity of movement (in the horizontal plane) of a lathe carriage, one may use a cylindrical centre arbor fixed between the centres of the lathe, the pedestal gauge being fastened to the carriage and the sensing tip of the gauge sliding along the cylindrical surface of the arbor.

7.4.3 Testing flatness

The flatness of surfaces of machine tools or of workpieces machined on such tools is tested with the aid of test plates, test straight edges or levels.

When testing flatness with a test plate, the plate must first of all be coated with a layer of paint. The flatness of the item tested can be judged from the distribution of the smears of paint on it after the thinly coated test plate has been placed on the surface to be tested and moved to and fro.

Tests of flatness with the aid of test straight edges are performed in the following manner (Fig. 10):

Support blocks of identical height are positioned at three corners of the rectangular test surface a,b,c, while a block of adjustable height is placed in the centre of the test surface.

The test straight edge is first of all placed on supports a and c, and the adjustable block is then brought into contact with its underside. The straight edge is then placed on support blocks b and c, the distance from the test surface to the straight edge at point d is measured, and the adjustable block is placed under the straight edge at that point.

After placing the straight edge on support blocks a and d and b and c, the distances from the straight edge to the intermediate points between a and b, b and c, a and b and d and a are then determined.

When checking the flatness of a surface with a level gauge (Fig. 11), the deviations from rectilinearity along the directions OA and OC are determined first, then the rectilinearity along the directions O'A', O''A''... and CB is verified. For checking purposes, the rectilinearity along the straight lines mM, and m'M'... is also verified.

7.4.4. Testing parallelism

To check the position of the axes of rotation of spindles, one should use cylindrical test arbors with conical ends (Fig. 12), which are inserted in the conical sockets of the spindles.

The axis of the cylindrical part of the arbor will not necessarily coincide exactly with the axis of rotation. To eliminate the influence of this divergence between spindle and arbor axes, the arbor is turned through 180° and the test of the position of the spindle's axis of rotation is repeated. The position of the axis of rotation is then taken as the algebraic mean of the positions recorded for the two settings of the arbor in the spindle.

The influence of the divergence between the axes of rotation can also be eliminated in another manner. The tip of the sensing rod of a gauge is placed against the cylindrical part of the arbor and, after slowly rotating the spindle, the spindle axis position is taken as the mean of all the values shown by the gauge.

In order to test the parallelism of two flat surfaces, a dial pedestal gauge is moved over one of the surfaces while the sensing tip of the gauge slides over the other surface (Fig. 13).

The parallelism of two axes in the same plane is tested by means of a dial gauge fastened on a base with a prism-shaped foot which is placed on one of the shafts whose parallelism is being tested, while the sensing rod of the gauge is placed in contact with the surface of the other shaft. In order to check the constancy of the distance between the axes, the foot to which the indicator gauge is attached is swung slightly, and the minimum reading of the gauge is noted. This measurement is repeated in a second plane, a certain distance away from the first plane of measurement (Fig. 14).

Testing the parallelism (absence of warping) of two axes in a plane perpendicular to the foregoing consists basically of testing the parallelism of each axes to a third auxiliary plane. When the axes to be tested are horizontal, they can be tested by means of a level placed on a bridge piece, the glass of the level being placed perpendicularly to them (Fig. 15).

The parallelism of a spindle axis to a plane surface is tested by means of a cylindrical test arbor inserted in the spindle socket and a dial gauge whose pedestal is moved on the surface (Fig. 16). The parallelism of a spindle axis to the guides of a machine tool can be tested in the same manner (Fig. 17).

The parallelism of the rectilinear trajectory of the movement of an element to a flat surface, a guide or an axis, as well as the parallelism of two rectilinear trajectories to each other is tested in a similar way.

7.4.5 Testing of the equidistance (constant height) with respect to a plane of two spindle axes or of an axis rotating around another axis in a perpendicular plane is effected by means of a dial gauge whose foot is moved on the flat surface, while its sensing rod is in contact with a cylindrical arbor inserted in the conical socket of the spindles to be tested (Figs. 18 and 19).

7.4.6 Testing for coaxiality

The coaxiality of two spindle axes is tested by means of a dial gauge whose bracket is fastened on one of the spindles, while its measuring rod is placed in contact with a cylindrical test arbor inserted in the conical socket of the second spindle (Fig. 20).

7.4.7 Testing for perpendicularity

When a straight line whose perpendicularity is being tested is the axis of rotation of a spindle or other element, its perpendicularity to a flat surface or to a guide is tested with a dial gauge which is fastened on the spindle a certain distance from the spindle axis and has its measuring rod in contact with the flat surface or with an element sliding on a guide (Fig. 21).

The spindle is turned through 360°, and the maximum and minimum readings of the dial gauge are noted. The difference between these readings, divided by the diameter of the circle described by the axis of the dial gauge holder, is an index to the deviation from perpendicularity. When the perpendicularity of a spindle axis to a guide is being tested, the spindle is rotated through 180° and the sliding element is moved a distance equal to the diameter of the circle described by the gauge holder (Fig. 22).

When testing the perpendicularity of plane surfaces and guides, a try square is used and the problem consists simply in determining the parallelism to the free side of the square. This also applies to testing perpendicularity to the direction of rectilinear movement.

7.4.8 Testing accuracy of rotation

Testing the accuracy of rotation consists basically of determining the radial divergence of the surface of a rotating part such as a spindle, the periodic axial displacement (axial divergence) of that part, and the "wobbling" of the end face of a part perpendicular to the axis of rotation.

One of the reasons for radial divergence of the surface of a rotating part may be irregularity of the shape (non-circularity) of that surface. Measuring the non-circularity of outer and inner rotating surfaces is not a simple matter, however, and calls for the use of complex special instruments.

Diameter measurements do not fully reflect the non-circularity of a surface, but they do enable its ovality to be evaluated.

Another reason for radial divergence of a surface may be the displacement of the geometrical axis of that surface with respect to the centre of rotation. Finally, radial divergence may be due to faults in rotary bearings which cause irregularity in the position of the axis of rotation (for example, the so-called "wandering play"). Where this is the case, the radial divergence does not coincide with a complete revolution of the spindle.

When checking the radial divergence of outer cylindrical or conical surfaces, the gauge is fixed so that the axis of its measuring rod is perpendicular to the generatrix of the surface (Fig. 23).

When testing the divergence of inner surfaces, such as that of the conical socket of a spindle, the shaft of a cylindrical test arbor is inserted in the socket and the divergence of the socket is evaluated from the divergence of the cylindrical part of the arbor.

In order to do this, the gauge is fixed in the vertical plane, first close to the end of the spindle, and then at the free end of the arbor. The divergence of the arbor is tested by rotating the spindle slowly. Afterwards, the test is carried out in the horizontal plane.

In order to eliminate the influence of any disparity between the axis of rotation and the axis of the arbor, these tests are carried out four times, the arbor being turned through 90° with respect to the spindle each time (Fig. 24).

When measuring the periodic axial displacement (axial wobble) of rotating parts (such as a spindle), the influence of any axial gap must be eliminated. In order to achieve this, a small axial load is applied to the end face of the part.

Measurement is effected by placing the axis of the measuring rod of the gauge coaxially with the part being checked. For this purpose an arbor with a flat end face (without any centre aperture), against which the measuring rod of the gauge rests, is inserted in the socket of the spindle (Fig. 25a).

This test can also be carried out by using a test arbor with a conical end, fitting a flat faced tip onto the end of the measuring rod of the gauge (Fig. 25b). If the rotating part has a centre aperture, a ball is inserted in this aperture and the flat face of the tip of the measuring rod of the gauge is placed against this ball (Fig. 25c).

End face wobble in a plane perpendicular to the axis of rotation is detected by means of a gauge fixed parallel to the axis of rotation at a given distance A from the axis (Fig. 26).

The part (spindle) being tested is slowly rotated while slight pressure is applied to it in the axial direction, and the readings of the gauge are noted at given intervals, such as 45°. The maximum difference between the readings at two opposite points then gives an indication of the end divergence at a circle of radius A.

7.5 Testing for temperature displacements

As already stated (section 2.4), temperature displacements in machine tools as the result of the internal generation of heat can have a substantial effect on the precision of machining.

In automatic lathes, these temperature displacements, together with tool wear, may lead to systematic changes in the diameter of the machined surface over a batch of workpieces, unless the machine tool is adjusted automatically or manually to compensate for this.

Similar phenomena are observed in turret lathes and other machine tools which do not have automatic correction, where the tool assumes a predetermined position with respect to the workpiece.

In many cases, temperature deformation of the machine tool may affect the shape of workpieces machined on it. For example, in the case of cylinder-and-cone grinding machines, local deformations of the frame under the influence of heat generated in the hydraulic drive of the table may result in faulty cylindricity of machined parts.

When it is necessary to check the temperature deformation of a machine tool, the tests consist in comparing the respective positions of the elements of the machine tool carrying the workpiece and the tool, first in the cold state and then after the machine tool has been warmed up by running light for a given period, such as three hours.

Thus, for example, in order to check the temperature deformation of a jig-boring machine, a test disc with an upper face and a cylindrical circumference which have been carefully checked for precision is placed on the table of the machine and a quickly detachable holder carrying two micron gauges is then fixed to the spindle of the machine tool. One of the gauges is vertical and its measuring rod is in contact with the flat face of the test disc, while the other is horizontal and its measuring rod is in contact with the cylindrical circumference of the disc (Fig. 27).

After the mounting of the test disc has been adjusted in such a way that when the spindle carrying the gauges is turned slowly both gauges (i.e. that coaxial with the axis of rotation of the spindle and that perpendicular to it) constantly register zero, the holder carrying the gauges is removed from the spindle and the machine is then run light for a certain length of time, such as three hours. The machine tool is then stopped, the holder carrying the gauges is replaced on the spindle, and the original measurements taken by slowly rotating the spindle by hand are repeated. The speed at which the spindle is rotated should correspond with the speed of rotation for the finishing machining of medium-sized apertures.

From the readings of the gauges it is possible to determine the horizontal displacement of the end of the spindle and the change in the inclination of the axis of the spindle as a result of temperature deformations of elements of the machine tool.

Where temperature deformations of a machine tool lead to changes in the geometrical shape of parts machined on it, it may be more useful to determine their influence by comparing the accuracy of the shape of several parts machined on a cold machine tool with the same number of parts machined after the machine tool has been warmed up under light running for three hours without being adjusted. This method of determining the effects of temperature deformations may be used for testing cylinder-and-cone grinding machines.

To check the temperature deformation of a lathe, tests should first be made of the parallelism of the axis of rotation of the spindle and the direction of longitudinal displacement of the carriage on the cold lathe; then the same tests should be made after the lathe has been warmed up by running it light for three hours.

8. Evaluation of the design of a machine tool from the point of view of longevity and long-term retention of initial accuracy

The longevity of a machine tool, and particularly the length of time that it will maintain its initial accuracy, depend very largely on the design of the machine tool and cannot be determined by tests of short duration. An indirect evaluation, based on consideration of those elements of the machine tool which have the greatest influence on its longevity, must therefore suffice.

In the overwhelming majority of machine tools, the maintenance of the machine's accuracy depends on the guides and the spindle bearings. In gear milling and gear cutting machines, the dividing worm drive is equally important, since wear of this part has a direct influence on the precision of the pitch of the gear wheels that are being machined.

The great diversity of the conditions in which machine tool guides operate makes it impossible to lay down general requirements which they must satisfy.

In the case of feed guides of medium-sized machine tools which are subject to heavy soiling, such as lathes, turret lathes and semi-automatic lathes, the wear is characteristically of an abrasive nature.

The guides of these machine tools must therefore be hardened. In some cases, cast iron frame guides are hardened by gas flame treatment or high frequency currents, while in others the actual guides consist of applied steel strips whose surface has been hardened by thermal or thermo-chemical means (cementation or nitriding).

For the guides of heavy machine tools, whose sliding parts are made of grey iron, the predominant form of deterioration is scoring. Over the past ten or fifteen years, most manufacturers of heavy machine tools have begun to use applied coatings on one of the rubbing surfaces of sliding elements. The materials used for these surfaces include various plastics and non-ferrous alloys which are not prone to binding against the cast iron surface with which they are in contact.

The main condition for the durability of sliding guides is protection from soiling. Wherever possible, therefore, protective devices (Fig. 28) such as telescopic covers, extensible bellows ("concertinas"), steel or plastic strips, etc., should be used. In addition to these protective devices, seals should be fastened to the ends of movable elements (Fig. 29). Another important condition for the long life of machine-tool guides is proper lubrication and the careful removal of impurities from the lubricating oil by allowing them to settle and by filtering finely. The machine-tool manufacturer should indicate the type of lubricants recommended for the lubrication of each machine tool in the technical literature which accompanies it.

If a machine tool is fitted with rolling guides, particular attention must be paid to the protection of such guides from soiling, as by their very construction they are even more sensitive to soiling than sliding guides.

In the case of rotary spindle bearings, proper lubrication is essential. The correct lubricant must be used for these bearings, and the requirements regarding the amount of lubricant applied to them must be observed in accordance with the manufacturer's directions, as any deviation from these directions may lead to premature failure of the bearings. Spindle bearings must be so adjusted as to avoid excessive heating on the one hand, while on the other hand avoiding excessive play when cold, which leads to "granulation" when machining.

In the case of sliding spindle bearings, as used mainly in grinding machines, the proper conditions for liquid friction must be set up, primarily by the running in of the bearing bushes (rings) over the whole range of spindle speeds.

When the lubrication conditions prescribed by the manufacturer are observed, the body of the bearing should not heat up by more than 15 - 20°C above the ambient temperature, for a peripheral speed at the journal of not more than 5 metres/second.

Annex 1

MACHINE TOOL PRECISION STANDARDS

Basic geometrical tests of general-purpose lathes with maximum workpiece diameter of 400 mm and maximum distance between centres of 2000 mm.

Description of test	Permissible deviation
1. Rectilinearity of longitudinal movement of carriage:	
(a) in the vertical plane	$\frac{0.02}{1000}$ only convexity is permissible
(b) in the horizontal plane	$\frac{0.02}{1000}$ only convexity towards the operator is permissible
2. Curvature of longitudinal movement of carriage	$\frac{0.02}{1000}$ 0.03 mm over whole length of carriage movement
3. Parallelism of tailstock guides to direction of longitudinal travel of carriage	$\frac{0.02}{1000}$ 0.025 mm over whole length of carriage movement
4. Radial deviation of centering collar of headstock spindle	0.01 mm
5. Radial deviation of axis of headstock socket:	
(a) at face of spindle	0.01 mm
(b) at a distance of 300 mm from face	0.02 mm
6. Axial deviation (axial periodic displacement) of headstock spindle	0.01 mm

7. Face deviation of supporting collar (or flange) of headstock spindle	0.02 mm
8. Parallelism of axis of headstock spindle to direction of longitudinal movement of carriage	
(a) in the vertical plane	$\frac{0.03}{300}$
(b) in the horizontal plane	$\frac{0.012}{300}$
9. Parallelism of direction of movement of carriage tool carrier slides to axis of headstock spindle (in the vertical plane)	$\frac{0.03}{100}$
10. Parallelism of axis of conical socket of tailstock spindle to direction of longitudinal movement of carriage, in vertical and horizontal planes	$\frac{0.03}{300}$ Free end of test arbor may only deviate upwards and towards operator.
11. Parallelism of movement of tailstock to direction of longitudinal movement of carriage:	
(a) in the vertical plane	$\frac{0.03}{300}$
(b) in the horizontal plane	$\frac{0.01}{300}$
12. Identity of height above frame carriage guides of axes of headstock and tailstock spindles	0.06 mm (only axis of tailstock spindle may be higher)
13. Precision of transmission system from spindle to lead screw, without use of gearbox	0.03 mm for a length of 100 mm 0.04 mm for a length of 400 mm

Testing of precision of machine tool in operation

(1) Accuracy of geometric form of outer cylindrical surface of testpiece after finishing cut	
(a) ovality	0.01 mm
(b) conicity	0.01 mm for a length of 100 mm
(2) Flatness of end surface of testpiece after finishing cut	0.015 mm for a diameter of 200 mm. Only concavity is permissible.

Basic geometrical tests of general-purpose column-and-knee milling machines

Description of tests	Permissible deviation
1. Flatness of working surface of table	$\frac{0.03}{1000}$ mm Only concavity is permissible
2. Relative perpendicularity of longitudinal and transverse movement of table in the horizontal plane	$\frac{0.02}{300}$
3. Parallelism of working surface of table to direction of its longitudinal movement	Over whole length of table travel: up to 300 mm - 0.015 mm " 500 mm - 0.020 mm " 1000 mm - 0.030 mm
4. Parallelism of working surface of table to direction of its transverse movement	Over whole length of table travel: up to 310 mm - 0.02 mm " 500 mm - 0.03 mm
5. Parallelism of side walls of centre groove of table to direction of table's longitudinal movement	Over whole length of table travel: up to 300 mm - 0.02 mm " 500 mm - 0.03 mm " 1000 mm - 0.035 mm
6. Axial deviation of spindle	For machines with diameter of spindle journal at forward bearing of: up to 50 mm - 0.012 mm " 80 mm - 0.015 mm over 80 mm - 0.020 mm
7. Deviation of end face of forward end of spindle	For machines with diameter of spindle journal at forward bearing of: up to 50 mm - 0.015 mm " 80 mm - 0.020 mm over 80 mm - 0.025 mm
8. Radial deviation of axis of conical socket of spindle	At face of spindle: 0.01 mm At distance L=150 mm from face: 0.015 mm (for machines with spindle journal diameter of up to 50 mm) At distance L=300 mm from face: 0.02 mm (for machines with spindle journal diameter of over 50 mm)
9. Radial deviation of outer cylindrical mounting surface of forward end of spindle	For machines with diameter of spindle journal at forward bearing of: up to 50 mm - 0.010 mm over 50 mm - 0.015 mm

Description of tests	Permissible deviation
10. **Perpendicularity of axis of rotation of horizontal spindle to centre groove of table**	0.02 mm for a length of 300 mm
11. Parallelism of axis of rotation of horizontal spindle to working surface of table	For machines with table width up to 160 mm - 0.02 mm for a length L=150 mm For machines with table width over 160 mm - 0.03 mm for a length L=300 mm Free end of test arbor may only deviate downwards.
12. **Perpendicularity of axis of rotation of vertical spindle to working surface of table**	1. For machines with table width of up to 160 mm: 0.015 mm for a diameter of 150 mm in the longitudinal plane; 0.020 mm for a diameter of 150 mm in the transverse plane. 2. For machines with table width of over 160 mm: 0.02 mm and 0.03 mm, respectively for a diameter of 300 mm. In the transverse plane, only inclination towards the frame is permissible..
13. **Perpendicularity of working surface of table to direction of vertical movement of knee in the longitudinal and transverse planes**	For machines with table width of: Up to 160 mm — Over 160 mm for a length of 150 mm - 0.015 mm — for a length of 300 mm - 0.020 mm along longitudinal axis of table; and 0.020 mm — 0.030 mm along transverse axis of table. In the transverse plane, inclination of the working surface is permissible only towards the frame.

Testing of precision of machine in operation

Dimensions of machined surfaces must be not less than:

For table working surface width of:	Breadth B	Length L	Height H
up to 160 mm	80	160	80
161 - 250 mm	100	200	100
over 250 mm	150	300	100

Description of tests	Permissible deviation
1. Flatness of machined surface:	0.02 mm for a length of 150 mm 0.04 mm for a length of 300 mm
2. Parallelism of upper machined surface to base	0.02 mm for a length of 150 mm 0.04 mm for a length of 300 mm
3. Perpendicularity of side machined surfaces to base	0.02 mm for a length of 150 mm
4. Relative perpendicularity to each other of side and end faces of testpiece	0.02 mm for a length of 150 mm 0.03 mm for a length of 300 mm

Basic geometrical tests for general-purpose cylinder-and-cone grinding machines with maximum workpiece diameter of 200-400 mm

The permissible deviations are shown for various categories of precision in machines

Description of test	Permissible deviation	
	For table travels of:	
	320-500 mm	500-800 mm
1. Rectilinearity of movement of table, measured in the vertical plane	5-12 microns Concavity of trajectory is not permissible.	6-16 microns
2. Rectilinearity of movement of table, measured in the horizontal plane	3-8 mic. Only permissible deviation from rectilinearity is towards grinding head	4-10 mic.
3. Absence of bias when table is rotated in plane perpendicular to its direction of movement	7.5-12.5 mic.	10-15 mic.
4. Parallelism of base surfaces of table (for heads and tailstocks) to direction of longitudinal movement of table	5-12 mic.	6-16 mic.
	For a maximum workpiece diameter of: 100-200 mm	200-400 mm
5. Absence of radial deviation of axis of headstock spindle socket:		
(a) at face of spindle	5-2 mic.	6-4 mic.
(b) at a distance L from face	3-8 mic. L=150 mm	6-10 mic. L=300 mm
6. Absence of radial deviation of outside base surface of end of headstock spindle	2-5 mic.	4-6 mic.
7. Absence of axial deviation of headstock spindle	1.2-3 mic.	2.5-4 mic.
8. Absence of deviation of face of base surface of headstock spindle	2.5-6 mic.	6-10 mic.

Description of test	Permissible deviation
9. **Parallelism of axis of headstock spindle socket to direction of movement of table** (a) in the vertical plane (b) in the horizontal plane	6-[illegible] mic. 12-2[illegible] mic. [illegible] mic. 6[illegible] mic. for a length for a length **of 200 mm** of [illegible]
10. **Constancy of height of axis of headstock spindle when headstock is rotated around its vertical axis**	15 mic. 20 mic. for a length of [illegible]00 mm
11. **Parallelism of movement of tailstock spindle to direction of movement of table** (a) in the vertical plane (b) in the horizontal plane	10 mic. 12 mic. 2-5 mic. 4-6 mic. over length of tailstock travel
12. **Parallelism of axis of tailstock spindle socket to direction of movement of tailstock spindle** (a) in the vertical plane (b) in the horizontal plane	6-10 mic. 8-10 mic. 3-5 mic. 4-5 mic.
13. **Parallelism (in the vertical plane) of a line running through the axes of the headstock and tailstock centres to the direction of movement of the table, along the length of grinding**	Length of travel [illegible]00-500 mm 500-800 mm 10 mic. 10 mic. over the whole length of grinding
14. **Absence of radial deviation of the centering collar of the grinding spindle at the grinding disc**	Diameter of forward journal: 32-50 mm 50-80 mm 3-6 mic. 5-8 mic.
15. **Absence of axial deviation of grinding spindle**	2-5 mic. 4-6 mic.
16. **Parallelism of axis of grinding spindle for internal grinding to direction of movement of table, in the vertical and horizontal planes**	10 mic. for a length of 100 mm Deviation of the free end of the test arbor is only permissible upwards and towards the axis of the centres.
17. **Identity of height of axis of headstock spindle and spindle for internal grinding above guides**	Maximum diameter of workpiece: up to 200 mm over 200 mm 6-16 mic. 12-20 mic.
18. **Rectilinearity and perpendicularity of movement of grinding headstock to axis of centres of headstock and tailstock spindles**	Maximum size of workpiece: up to 200 mm from 200 to 400 mm 4-6 mic. 5-8 mic.
19. **Constancy of height of axis of grinding spindle when spindle is turned around its vertical axis**	From 100 to 200 mm from 200 to 400 mm Protrusion of test arbor, L=100 mm 15 mic. 20 mic.

Description of test	Permissible deviation	
20. (a) Accuracy of movement of grinding headstock through one scale division and through 10-12 scale divisions	From 100 to 200 mm 5-12 mic.	from 200 to 400 mm 10-16 mic.
(b) Constancy of position of grinding headstock when set in a given position	1-2.5 mic.	1.5-2.5 mic.
Testing of machine tool in operation		
A. Precision of cylindrical surface of testpiece (constancy of diameter at any cross-section). Work between centres. Diameter of testpiece $d > \frac{1}{8} D$ 1. Length $L = D$ (D = maximum diameter of workpiece, in mm)	3-8 mic.	7-11 mic.
For machines with rotatable headstocks		
2. Testpiece - a roller of dimensions $d > \frac{1}{8}D$, $L = \frac{1}{2}D$ - is fastened in the chuck or in the spindle socket and its outer cylindrical part is machined	3-8 mic.	7-11 mic.
3. Testpiece - a bush of cylindrical form with $d_1 > \frac{1}{2}d_{max}$ and $L = 2d_1$ - is fastened in the chuck and its inner cylindrical surface is machined	3-8 mic. Permissible deviations from constancy of diameter at any cross-section must be not more than 40% of those shown.	7-11 mic.
B. Flatness of end surface of testpiece. Testpiece is a disc fastened in the chuck and machined on its end surface.	Maximum diameter of workpiece: 100-200 mm 4-6 mic. Convexity is not permissible.	 200-400 mm 6-8 mic.

Note: The permissible deviations are given in most cases in the form of a range of values which are applicable to machine tools of various degrees of precision.

Annex 2

Information on the purpose and selection of machine tools

Metal-working equipment is notable for its great variety in:

1. The tools used (drills, reamers, taps, cutters, milling cutters, shavers, abrasive and polishing discs and so forth).
2. The types of work carried out (boring, milling, drilling, gear cutting, grinding, polishing and so forth).
3. The degree of finish of the machined surface (varying from rough finished to highly finished).
4. The dimensions of the machine (varying from table top machines to large units which machine parts several tens of metres in diameter and hundreds of tons in weight).
5. The precision (varying from machine tools of normal accuracy to high precision machines).
6. The range of parts machined (there are, for example, universal machines, multi-purpose machines, specialized machines and specially designed machines).
7. The number of tools used at the same time (there are single and multi-spindle machines, multi-carriage machines and multi-cutter machines).
8. The number of parts which can be machined at the same time (single and multi-station machines).
9. The degree of mechanization and automation (varying from machines which are continually controlled by an operator to those which are fully automated).
10. Their design features (vertical, horizontal, drum-type, single or double-sided, pendulum type, multi-elements and so forth).
11. Additional operating features (stationary, portable).

The selection and comparison of such varied equipment is made easier by the fact that the machine tool industries which have evolved over a long period of time in all industrially developed countries all produce machines which are similar in a number of basic characteristics.

Of the machine tools used in one-off, limited series and series production, the most common are universal machine tools which are suitable for carrying out a number of operations of a given type of machining on workpieces of various denominations. Machine tools of this type are relatively inexpensive, have wide range of spindle speeds and feed rates, and are simple to adjust and service, but their technical capabilities can only be properly exploited if fully skilled operators are available.

Unless there is special equipment for this purpose, these operators must know how to set up, check and fasten the workpiece properly in the machine tool, adjust the cutting tool and carry out the machining, controlling the machine tool manually and taking the necessary measurements. On such machine tools, the quality of the machining and the output largely depend on the skill of the operator.

Examples of such universal metalworking machine tools are general purpose centre lathes, column-and-knee milling machines, shaping machines, vertical drilling machines and cylinder-and-cone grinding machines.

Specialized machine tools are intended for the machining of workpieces of a single type, although of various dimensions. They are designed to facilitate speedy and accurate setting-up of the workpiece and are usually intended for simultaneous machining of the workpiece with several tools, which secures high productivity, but they can only be used effectively if there are large enough batches of workpieces to be machined.

Special machine tools are designed for the machining of only a single type and size of workpiece.

Extensive use is made of high-production specialized and special purpose machine tools at the present time in such branches of industry as the automobile and tractor industry, the aviation industry, the bearing industry, the electrical machinery industry, the shipbuilding industry, the agricultural machinery industry, the transport machinery industry and so forth.

Efforts to reduce the design and production time for special purpose machine tools, which are produced only to special order, and efforts to reduce costs and simplify repairs and servicing, while securing a high degree of reliability and automation of machining, have led to the development of the group of so-called composite machine tools. The design of such machine tools is based on the principle of the use of standardized elements, some of which may occur a number of times in a single machine tool, thus making it possible to construct multi-spindles and multistation machines.

The first automatic machine tool lines were created by linking several composite machine tools with an automatic conveyor system.

The selection of a machine tool of the requisite dimensions is carried out according to the main technological parameters which, for the basic types of universal machine tools used for mechanical engineering machining are as follows:

Table 1

Type of machine tool	Main technical parameters
1. Lathes, screw-cutting lathes and gear-milling lathes	Maximum diameter of workpiece above frame, maximum length of workpiece (distance between centres).
2. Multi-cutter semi-automatic lathes (horizontal and vertical)	Maximum diameter of workpiece above frame or carriage.
3. Turret lathes, single-spindle automatic lathes and longitudinal machining automatics	Maximum diameter of bar which can be machined.
4. Multi-spindle automatic and semi-automatic lathes:	
(a) for bars	Maximum diameter of bar which can be machined and maximum length of part which can be machined.
(b) chuck-type machines	Maximum diameter and length of part which can be machined.
5. Facing lathes	Maximum diameter of workpiece.
6. Vertical boring and turning machines	Maximum diameter and height of workpiece.
7. Vertical and radial drilling machines	Maximum rated drilling diameter for medium carbon steel.
8. Centre boring and milling machines	Maximum diameter and length of workpiece.
9. Horizontal boring machines	Diameter of boring spindle.
10. Jig-boring machines	Diameter of table if circular or width and length if rectangular.
11. Diamond boring machines	Width and length of table.
12. Cylinder-and-cone grinding machines	Maximum diameter and length of workpiece.
13. Centreless grinding machines and centreless lapping machines	Maximum grinding diameter.
14. Internal grinding machines	Maximum diameter of aperture which can be ground.
15. Surface grinding machines	Width and length of table if rectangular or diameter if circular.

16.	Rough grinding machines	Diameter of grinding disc.
17.	Slot grinding machines, thread and worm grinding machines, superfinishing machines and outside honing machines	Maximum diameter and length of workpiece.
18.	Internal honing machines	Diameter which can be honed and length of travel.
19.	Buffing machines	Diameter of buffing head.
20.	Sharpening machines (universal)	Diameter and length of workpiece.
21.	Gear milling machines, gear cutting machines, gear shaving machines, gear grinding machines, gear shaping machines and gear chamfering machines for cylindrical and conical gear wheels	Maximum diameter and form of module of workpiece to be machined.
22.	Slot milling machines	Maximum diameter and length of workpiece.
23.	Rolling and cold working machines	Maximum diameter of workpiece.
24.	Horizontal and vertical column-and-knee milling machines and copy milling machines	Width and length of working surface of table.
25.	Single- and double-sided plano-milling machines	Width and length of working surface of table.
26.	Rotary table milling machines	Diameter of table.
27.	Single and double sided planing machines	Maximum width of workpiece and length of working surface of table.
28.	Edge planing machines	Maximum width and length of workpiece.
29.	Shaping machines and slotting machines	Maximum slide travel and maximum shaping width.
30.	Horizontal and vertical broaching machines	Rated tractive force in tonnes.
31.	Cutting-off machines	Maximum diameter of material which can be cut.
32.	Screw-cutting machines	Maximum dimensions of threads which can be cut.
33.	Dynamic balancing machines	Range of weight of parts to be balanced.

Changes in the main technical parameters, on which the dimensions of the machine tool depend, are subject to well defined rules.

The selection of a number - preferably limited - of different types and sizes of machine tools for a factory is usually carried out according to an arithmetic or geometric progression with variable denominators based on the frequency of the series of main technical parameters. The more frequent series (for small values of the denominator) thus correspond to the range of the more frequently used types and sizes of machine tools.

In the case of an infrequent series, the consumer is obliged to select heavier and more expensive machine tools than those which directly suit his requirements as far as size is concerned. In the case of a very frequent series, on the other hand, the production run of each machine tool is diminished and its overhead costs are consequently higher.

Types of machine tools whose main technical parameters correspond to the terms of a whole series are basic machines. These basic models are modified in such respects as precision, level of mechanization and automation, certain dimensional parameters, speed of operation and weight (for the machining of non-ferrous metals and alloys) and so forth.

LATHES

Universal screw-cutting lathes of medium dimensions are most frequently met with in this group.

On a screw-cutting lathe, any metal-turning operations can be effected by fastening the workpiece in a chuck or between centres. Among the operations which can be carried out are cylindrical and conical turning, the undercutting of end faces, the cutting of inch or metric screw threads, and boring out. By inserting a drill in the tailstock spindle socket, it is possible to carry out drilling operations by using the manual feed of the tailstock spindle or moving the whole tailstock forward mechanically.

Lathes and screw-cutting lathes are used both in the production and repair departments of large and small machine-building factories, as well as in small workshops and repair centres.

The constantly improved design of these machine tools reflects the general technical progress of industrial production and the rising demand for lower production costs and economy in the use of manpower. Over the last ten to fifteen years, the technical characteristics and design of lathes have been modified to increase their power, running speed and precision, and to reduce the time spent on auxiliary operations.

In order to increase the static and dynamic rigidity of lathes, their body elements have been made heavier, spindles have been provided with three bearings, and tailstock spindles have been strengthened and in some models made prismatic or triangular in shape.

The main type of transmission mechanism used in the main drive is still a gear-box with movable gear-wheels, but direct belt drive of the spindle, independently of the position of the gear-box, is being used more and more frequently in lathes.

The use of electromagnetic clutches in change-speed gear-boxes makes gradual speed changes possible by cheaper means than the use of variable (stepless) transmissions.

Electromagnetic clutches make it possible to change gear during machining, to maintain a constant speed of machining, and to exercise remote control.

Table 2

Technical characteristics of several models of universal screw-cutting lathes

Technical parameters	Basic dimension: maximum diameter of workpiece which can be machined above frame, in mm										
	100	125	160	200	250	320	400–450	500–550	630	900	1000–1200
1. Maximum length of workpiece – distance between centres, in mm	125	185	250	350–	500	500– 1000	710–1000 1400–2000	1000– 2000	1400– 2800	2300	5000
2. Speed range of spindle, in revolutions per minute	630– 6300	530– 5300	70– 4000	44– 3000	30– 3000	11– 2240	15–1500 12.5–2000 38–2500	11.5 2000	10 1250	7.5–750 10–1300	5–500– 600
3. Transverse feed range, in mm/rev	–	–	0.01– 0.3	–	0.05– 0.7	0.08– 2.6	0.03–2.0 0.07–4.0	0.07– 4.00	0.1– 3.2	0.2– 3.05	0.2 3.05
4. Power of electric motor of main drive, kW	0.12	0.6	1	1	1.7	4.5	7.5–10 –15	10	14	20	28
5. Weight of machine, kg	25	210	420	565	560	1500	2000 –2400	3000	4000 –5000	8000 –12000	14000

Table 2 shows the general technical characteristics of universal lathes of the most common types and sizes.

As a rule, lathes are manufactured in various frame lengths which permit wide variation of the maximum distance between centres. There are also certain models of lathes provided with an adjustable frame which can be slid along the base, thus enabling the distance between centres to be increased still further.

In order to increase the maximum permissible diameter of workpieces, provided that the latter are relatively short, wells are made in the forward part of the frame in front of the chuck. Sometimes the frame is "stretched" to accommodate large diameter workpieces which are not too heavy by inserting packing pieces under the headstock and tailstock.

The equipment of universal lathes with copying mechanisms - mostly hydraulic - permits automation of the machining cycle, and this is particularly advantageous in the case of series production. The same objective is served by the preselection mechanisms used on a whole range of machine tools for the preselection and rapid change of gear wheels and the adjustment of the number of revolutions to a given value to suit a given machining speed and a given workpiece diameter.

Semi-automatic copying lathes noted for the high degree of automation of their operating cycle, their increased power and higher maximum running speeds have become more and more widely used in industry in recent times.

The latest advance in the automation of machine tools is their equipment with programmed control mechanisms, the simplest of which consist of electric plug panels, drums with pegs, etc. These mechanisms programme only the sequence of the separate elements of the cycle, the actual form of the finished workpiece being determined in such cases by a pattern or template followed by means of a servo-system.

For instrument manufacture and other precision work, lathes of higher precision are produced. The increased precision of these lathes is achieved through the use of high precision bearings and the more careful manufacture of all the vital parts. Instrument-making lathes are characterized not only by their high precision, but also by their greater technological capabilities, and particularly by their wider spindle speed range and their wider range of feed rates.

Heavy lathes with a workpiece diameter of 1,250 mm or more are manufactured in two or three different models for machining heavy, medium and lightweight parts. The roughing and finishing machining on lathes is carried out by tools made of high-speed steel and hard alloy steel.

Direct-current electric motors are frequently used for the main drive of lathes, and the total power of all the electric motors with which a lathe is equipped may be several hundred kilowatts. Lathes can usually be controlled from several points.

Copying mechanisms are used on lathes for the machining of complicated curved or stepped profiles. For cutting screw-threads, a synchronous electric drive is employed.

In addition to the lathes and screwcutting lathes used in industry, turret lathes are also in wide use for the mass production of small steel parts directly from bars.

The mechanism for feeding and holding the bar takes various forms, depending on the diameter of the bar to be machined and the design of the lathe: the feed and gripping may be manual, through a lever and weight; through a spring mechanism; through a pawl drum, by means of an electric drive with push-button control; by hydraulic means and so forth.

The advantage of these machine tools is that they can be set up for simultaneous machining by several tools mounted in a turret head with a vertical or horizontal axis as well as by tools mounted on transverse carriages, they can carry out a semi-automatic machining cycle, and they do not require highly skilled operators.

Once the machine tool has been set up for machining a batch of parts, the operator can quickly become familiar with the necessary control operations and can attain high productivity.

The operator's work is made easier by the fact that whereas on earlier turret lathes the gear changing was manual, and thus time-consuming and tiring, the requisite number of revolutions per minute is now selected in advance and the speed is regulated by means of a single handle. The use of friction clutches makes it possible to change the drive ratios while the machine is in motion, without switching off the electric motor, and this reduces the amount of time spent on auxiliary operations.

Single and multi-spindle automatic turret lathes are designed for the production of parts from cold-drawn precision rod and are used in large-series and mass production. By means of the group setting method, they can also be effectively used in small-scale production.

If automatic lathes are fitted with several transverse carriages and turret heads and also with various extra attachments, they can turn out complex-shaped parts at a high rate.

Longitudinal-machining automatic lathes are widely used in the instrument-making, watch-making and other branches of industry.

Turret lathes are also produced in versions fitted with chucks. A batch of ten to thirty parts is an economic size for machining on well equipped turret lathes or semi-automatic turret chucking lathes, which have displaced ordinary lathes in many factories engaged in series production. The power of the main drive in semi-automatic turret lathes is as much as 30 to 45 kilowatts.

By using a large number of cutting tools which move simultaneously along identical paths, semi-automatic multi-cutter lathes make it possible to machine parts to their requisite shape in short simultaneous cycles of operation of several carriages. These semi-automatic machine tools, which are of relatively simple design, are used for machining parts which are not too complex in shape, either between centres or in a chuck, in large-series and mass production.

Semi-automatic hydraulic copying lathes usually machine the required shape with a single cutter and can easily be readjusted by changing the pattern or template and changing the tool setting.

When semi-automatic hydraulic copying lathes have a sufficiently powerful main drive, the cutting capabilities of hard alloy tools can be used to the full.

Facing lathes are used for the machining of parts such as rings and discs which are of large diameter (several metres) but are of relatively small thickness or height.

Wider use is made of vertical boring and turning lathes, on which workpieces which are not only of large diameter but also of considerable height and weight can be conveniently fixed and machined.

Designers are paying great attention to the mechanization and automation of the control, clamping and release of the carriers and slides and the movement of the carriages of those machine tools. In addition, vertical boring and turning lathes are now being designed to incorporate systems for the electronic measurement of the operational displacement of their main elements.

As well as universal machine tools, machine tool factories are producing specialized and special-purpose lathes which have attained a high degree of development in countries with automobile, tractor, and shipbuilding industries, railway equipment and metalworking machinery, construction and other branches of industry. These machine tools are designed for lathe-machining crankshafts and camshafts, for turning the bars and rollers of rolling mills, for cutting tubes and sleeves, for turning axles, wheels and wheel couples, for railway rolling stock, and for turning the backs of turbine blades, bearing rings, and other parts.

When selecting and importing machine tools, whether universal or specialized, developing countries must always consider local conditions and the prospects for the development of home industry.

As a guide, the table below provides a schematic classification of the various types of machine tools in the lathe group and indicates the field of utilization of the main types.

Table 3

Lathe group of machine tools

(basic types and sizes and technical parameters of machines produced by the machine tool industry, summarized for guidance)

Type of machine tool	Technical parameters, in mm		Uses
	Max. diam.	Max. length of workpiece	
1. Table and pedestal lathes	100-160	125-250	Watchmaking, instrument-making and precision mechanics industries
2. Medium-size screw-cutting lathes	200-1000	500-3000	One-off and series production; repair departments and workshops
3. **Heavy** lathes	1250-6300	up to 20,000	Heavy machine construction
4. Turret lathes	18-100	---	Series production of parts from bar or from individual workpieces
5. Semi-automatic chucking turret lathes	160-500	---	Large-scale machining of parts in large-series and mass production
	Max. diam. of bar	Max. length of part machined	
6. Single-spindle automatic turret lathes	8-65	60-90	Large-series and mass production of parts from round, square and hexagonal bar stock
7. Single-spindle automatic longitudinal machining and shaping lathes	3-40	50-80	Production of precision parts of complicated shape from cold-drawn high-precision bar for the watch-making, instrument-making, optical, electrical and other branches of industry
8. Multi-spindle automatic horizontal bar lathes	10-140	150-200	Various lathe operations in large-series and mass production

Table 3 (cont'd)

		Max. diam. of workpiece	Max. length of workpiece	
9.	Multi-spindle semi-automatic horizontal chucking lathes	50-250	up to 200	Various lathe operations in large-series and mass production
10.	Gear-milling lathes	520-690	710-1000	Quantity machining of hobbing cutters, cutting discs and profile cutters and of tools with straight, oblique and end-milled cutting edges
11.	Semi-automatic multi-cutter centre lathes (horizontal and vertical)	125-600	300-2000	Large-scale roughing and finishing machining of parts such as stepped shafts, etc. High productivity is achieved through the high power of the drive, the rigid construction, and the multiple cutting tools.
12.	Facing lathes	1400-8000	---	Machining of thin large-diameter parts such as rings and discs made of ferrous or non-ferrous metals
		Max. diam. of workpiece	Max. height of workpiece	
13.	Vertical boring and turning lathes	800-25,000	800-6300	Machining and boring out of cylindrical and conical surfaces machining of grooves, drilling, reaming and turning of heavy (up to 500 tonnes) workpieces for the heavy-machinery construction industry.

Drilling machines

This group of machine tools comprises vertical drilling machines (including table drilling machines), radial drilling machines (including transportable machines), deep drilling machines (both vertical and horizontal), screw-cutting machines, centre boring machines, and automatic and semi-automatic centre milling machines. Operations such as drilling, counterboring, broaching, reaming and screw tapping can be performed on these machines.

The main designs of drilling machines are vertical column drilling machines and radial drilling machines. The first type is for drilling holes in small workpieces held in jaws or in jigs, and the axis of the spindle and tool is fixed. The second type is for drilling holes in heavy, bulky workpieces, when it is easier to move the drilling head than the workpiece to pass from one hole to another.

The increased demand for precision, rigidity and vibration-resistance in machine tools has led manufacturers to produce radial drilling machines with additional supports, rectangular tables moving between co-ordinates, and round revolving tables, and in recent years drilling machines of the portal type have been produced.

In order to increase the productivity of labour of drilling-machine operators, these machines are provided with turret tool heads and in some cases with automatic tool change, while co-ordinate cross tables are equipped with mechanisms to automate the displacement of the table between co-ordinates when machining.

The use of programmed control ensures fully automated control of the sequence of operations, the establishment of the co-ordinates, the setting of the tool and the halting of the machining process when completed.

The main movements of machine elements are being mechanised to an increasing degree, particularly on heavy machine tools. For example, large radial drilling machines usually have mechanised movement of the drill head in the sleeve as well as mechanised clamping of the drill head, the sleeve and the column. All the controls are situated within easy reach of the operator. Many firms produce machine tools on which only the final fine setting of the spindle head support is done manually. On some models, the movement, turning, raising, lowering, clamping and release of the sleeve, pole-changing and adjustment of the rotation of the spindle drive, as well as engagement of the feed when drilling or screw threading, are all carried out by manipulating a single handle.

On all-purpose universal machines, the sleeve carrying the drilling head can be turned through 360° and adjusted for height in a direction parallel to its axis. The drilling head can be fastened in any position from +90° to -90°, and the feed stops automatically at a pre-set depth.

Modifications of vertical and radial drilling machines are also produced for co-ordinate drilling work. Such machines are cheaper than the corresponding types and sizes of boring machines and give satisfactory machining results when high precision of positioning without a jig is not required.

In series and large series production, multi-spindle line machines with 4 - 8 or more spindles are used for the successive machining of one or more holes with different tools. Vertical drilling machines with multi-spindle bell-type heads are also used in the same type of production. The spindles are articulated and change position to suit the position of the holes in the workpiece. Machine tools, in which the cutting tool is a wire-like drill working with abrasives, are being produced to satisfy the requirements of special branches of industry for the drilling of small-diameter holes in extremely hard materials. These drills not only rotate rapidly but also simultaneously vibrate in an axial direction, and in an eight-hour day a machine tool fitted with them can drill 200-400 holes.

Automatic centre milling machines may be used for the centre boring and undercutting of the end faces of workpieces in machine-building factories where the length of the production run is variable. These machines simultaneously mill both end faces and thus ensure parallelism. The perpendicularity of the centre milling to the end faces makes further machining unnecessary, and only finishing undercutting is needed.

Table 4

Drilling machines and similar machine tools

(basic types and sizes and technical parameters of the machines produced by the machine tool industry at present, summarized for guidance)

Type of machine	Technical parameters		User
	Drilling diam. mm	Number of revs/ min	
1. Table drilling machines	1.5-25	up to 15,000	Drilling, counterboring, reaming of holes in small workpieces
2. Vertical drilling machines	18-75	up to 3,000	Drilling, counterboring, reaming and screw tapping of workpieces held in a clamp or jig
3. Vertical drilling machines with extensible spindles (up to 48)	from 6	up to 1,500	Simultaneous drilling of groups of holes
4. Movable radial drilling machines	25-75	10-1500	Drilling operations in different planes on large, heavy workpieces
5. Radial drilling machines	35-100	25-2500	Drilling operations on workpieces clamped in place
6. Co-ordinate drilling machines	up to 30 or more	up to 1500-2000	Drilling, milling and boring operations at lower level of precision than with jig-boring machines
7. Automatic and semi-automatic centre boring and centre milling machines	Max. diam. and length of workpiece from 10 x 130 to 125 x 2000	up to 5000:- drilling: up to 1200; milling: up to 700	Drilling, centre boring and milling of end faces of workpiece

Boring machines

In this group we find horizontal boring machines, jig-boring machines, diamond-tipped boring machines and composite machines, and also machine tools for deep drilling and boring as well as various specialized machines.

The main trend in the design of boring machines, which has been particularly marked in recent years, is to increased precision and productivity and towards further extension of the technological possibilities of horizontal boring machines.

Modern horizontal boring machines have drives of higher power which enable them to do high-production milling as well as boring. These machines have rigid, solid frames, supports and spindle elements which give them adequate vibration resistance when carrying out heavy milling operations. They are also equipped with various accessories and items of auxiliary equipment (round tables, copying equipment and so on).

By the use of direct-current electric motors, whose speed can be regulated over a wide range, the feed rate can be changed during the machining process and the kinematics of the machine tool can be simplified. The fact that the main drive can be regulated makes it easier to select the optimum machining speeds to fit the actual conditions.

A suspended control panel, with devices for visually checking the co-ordinates of movement, enables the operator to control the machine tool from any point which is convenient to him during the machining process.

The following improvements have been made by designers to increase labour productivity on horizontal boring machines:

Increased running speed;

Higher level of mechanization and further perfectioning of the control system and of the reference and measuring system;

Provision of machine tools with individual lifting devices to mechanize the fitting and removal of accessories and heavy tools (milling cutters, mandrels, etc.).

The use of multi-position drums with inserted pegs, adjusted in accordance with the reference and measuring system when the first part is machined, provides the basis for the mechanization of subsequent repeated co-ordinate displacements of the elements of the machine tool when machining a batch of identical parts.

Measures to increase the precision of horizontal boring machines have proceeded along two lines: construction of high-precision models as accurate as jig-boring machines, and further improvement of the precision of ordinary boring machines. This latter improvement in precision has been effected by the use of higher-precision measurement scales and optical measuring attachments, by reducing temperature deformations (particularly temperature displacements of the spindle axis in the machining process), and by increasing the precision of slow machine movements.

Several firms have begun to produce precision horizontal boring machines for boring holes in solid workpieces. On these machines, the co-ordinates are set up by means of narrow horizontal and vertical strips with holes in which pegs defining the movement of the table and of the spindle block are inserted.

Universal horizontal boring machines of small and medium sizes are manufactured with a fixed support, while those of large sizes are produced with a support which is movable in the longitudinal direction. On particularly heavy machines the forward support is movable in both the longitudinal and transverse directions.

Table 5 provides a guide to the technical characteristics of horizontal boring machines produced by the machine tool industries of various countries.

These machines may be used in industrial production and in repair shops for the boring of holes in solid workpieces. They need to be operated by skilled workers.

A considerable number of modern horizontal boring machines are equipped with programmed control, which saves labour and increases the productivity of boring machine operatives.

Jig-boring machines are used in both one-off and series production and enable precision boring operations to be carried out in accordance with co-ordinates without the use of expensive guidance equipment.

On these machines the co-ordinates can be established to within a precision of 2 - 5 microns (depending on the size of the machine) through the use of precision-divided index scales, optical measuring devices and interpolating reference systems. The high precision of jig-boring machines is achieved through the increased rigidity of their frame elements, the reduction of heat deformations and of chance errors and the use of wear-resistant rolling guides, which considerably increase the sensitivity attainable in displacements between co-ordinates.

Table 5

Technical characteristics of some models of universal horizontal boring machines

Technical parameters	Basic dimension : diameter of extensible spindle in mm									
	Models with fixed forward support					Models with forward support movable in a single direction			Models with forward support movable in two directions	
	65	80	85–90	100–110	125–127	150–152	160	175–177/8	220	320
1. Dimensions of table - fixed plate, in mm	710x900	800x1000	900x1120 1120x1300	1120x1300 1260x1400	1250x1600 1500x1800 1220x1830	1800x2250 1220x2130	1800x4500	4200x4600	5000x8100	5000x8100
2. Number of revs. per minute of spindle	16–2000	20–1600	12.5–2000 15–1500	12.5–1600 9–1400	8–1250 5–1000 5.6–1020	7.5–900 5.6–1020	8–600	7.5–950 2–400	1–510	0.5–259
3. Axial feed rate of spindle, mm/min	2.2–1750	2.2–1760	0.25–1200 2.2–1760	2.2–1760 0.18–1680	2–800 10–2000 0.3–3050	2–1500 0.3–3050	1–1000	2–1500 13–3200	1–400	0.5–300
4. Power of main drive, kW	5.2–7	5.5	7.5–10	7.5–10 14.7	14 18.5 22	14 22	42	14 30	55	100
5. Weight, tonnes	6	7	12.5	12.5 16	28.8 31.5 29.7	52.2 33.8	65.5	42.2 42.5	141	262.6

Improvements in the design of jig-boring machines with a view to increasing productivity and convenience of operation have been directed towards the mechanization and automation of the movement of the machine's working parts, the preselection of co-ordinates, the regulation of running speeds and feed rates, and the mechanization of tool changes.

Increasingly wide use is being made of various systems of programmed control, to automate control of the cycle of co-ordinated displacements of the table and carriages and rule out the possibility of operator error.

A number of firms are producing semi-automatic machines on which the whole machining cycle - including the rapid approach, working feed and rapid withdrawal of the spindle, the change of machining rates, tool changes and co-ordinate changes of the working parts - is automated.

These semi-automatic machines are complicated in construction and are not yet in wide use.

Where high precision is not required, it is advisable to use cheaper machine tools of lover precision (0.02 mm), which have a sufficient degree of mechanization to yield high labour productivity. These machines permit preselection of running speeds and feed rates and precise establishment of pre-selected co-ordinate positions by automatic means and they are fitted with push-button control of the adjustments of the various machine elements.

Generally speaking, jig-boring machines are produced in a wide range of sizes and in various classes of precision, so as to allow rational selection of the kind of machine suitable for the production conditions.

Horizontal and vertical fine boring (diamond boring) machine tools are used for the fine boring and machining of cylindrical surfaces, and are the most economical for large-series and mass production. Usually, these machine tools are already set up for the machining of a particular part when purchased.

Composite machine tools of the most varied composition, consisting of working heads arranged in various ways (vertically, horizontally, slantwise, in rows, in circles and so forth) are also produced, for use in large-series and mass production.

The group of specialized drilling and boring machines intended for the machining of parts in large-series and mass production includes machines for deep drilling and boring, machines for boring out the grooves of rolling mill rollers, machines for boring out the bearing housings in the cylinder blocks of internal combustion engines, machines for boring out the big and small ends of connecting rods, and many others.

Milling machines

The main types of machines in the milling-machine group are as follows:

1. Column-and-knee milling machines: General-purpose machine tools.
   1.1 Horizontal machines - with revolving table (universal) and with fixed table.
   1.2 Vertical machines - with fixed head or with rotating head.
   1.3 All-purpose machines.
2. Columnless machines (with rectangular or built-in round tables)
3. Plano-milling machines (with rotating or fixed milling carriages), single-sided and double-sided.
4. Milling and cutting machines.
5. Specialized machine tools:
   5.1 Turret-type milling machines
   5.2 Drum-type milling machines
   5.3 Copy milling machines for various branches of machine construction.
6. Special machine tools.

The most numerous group of milling machines (up to 60-70 per cent of the total) is that comprising column-and-knee milling machines of horizontal, vertical and universal type, which are produced by a large number of firms. They are so named because the table and carriages are mounted on a column.

General-purpose column-and-knee milling machines are produced in the form of horizontal machines with rotating or fixed tables, of vertical machines, on the basis of which copy milling machines are constructed, of machines with programmed control and so forth.

Small column-and-knee milling machines - with a table width of 100-160 mm - are intended for the machining of small workpieces made of non-ferrous metals and alloys or plastics, and for the finishing milling of parts made from steel or cast iron.

The longitudinal, transverse and vertical feeds on these machines may be either mechanized or manual. On automated machines used in series production, the longitudinal feed of the table is carried out from a drum actuated through the gearbox.

On machines with a table width of 200 mm or more, the movement of the table in all directions is mechanized, and the machine can use both milling cutters of high-speed steel and those provided with blades of hard alloy. The technological capabilities of the machines are increased if various additional accessories (universal dividing heads, extra cams for the control of automatic cycles, etc.) and extra heads (universal milling heads, boring heads, slotting attachments and grinding heads) are obtained from the supplying factory at an extra charge. The manufacturers also produce high-speed modifications of machines which differ from the basic models by their more powerful electric drive and their increased range of speeds and feed rates.

All-purpose models with a milling head which can be turned in two planes and a universal rotating table are also manufactured. These machines are based on horizontal column-and-knee milling machines and are equipped with racking and slotting heads besides the usual accessories and auxiliary equipment. All-purpose milling machines are of high precision and are mostly used in the tool-making, instrument-making and repair shops of machinery manufacturing works.

Columnless milling machines with cross tables have a more rigid table construction than column-and-knee milling machines, which enables them to machine workpieces of large size and weight.

Copying milling machines are produced on the basis of either column-and-knee or columnless types of milling machines, and they may have vertical or horizontal arrangement of the spindle.

Engraving copy milling machines for copying according to two co-ordinates (in a single plane) and for three-dimensional copying can do light milling work (the milling of shallow press dies, flat templates, patterns, etc.) and engraving of nameplates, designs and figures. In these machine tools, the tracing finger is moved manually and the operating principle is based on the reproduction of designs or shapes.

In the copy milling machines produced by machine tool firms, mechanical, electro-mechanical, and hydraulic copying systems are used.

In order to increase productivity in copying work, machines produced in the last few years have shown a trend towards more powerful main drives, a wider range of spindle speeds and the use of two or more spindles.

The requirement for powerful and rigid copy milling machines has led to the development of the columnless milling machine as the basis for copy milling models.

In industrially developed countries, column-and-knee milling machines have been automated by the use of programmed control systems, which enable the setting-up time of the machine to be shortened and enable one operator to look after several machines.

In the simplest systems of automatic control, programming is effected by means of plug-in units placed one after another on the control panel in order to secure the proper sequence of operations. The magnitude of each movement of the elements of the machine is defined by the distance between stops.

Universal plano-milling machines are used in one-off and series production for the machining of large-dimension solid-type workpieces of cast iron, steel or non-ferrous metals.

These machines are produced in single-support and two-support form, the first of them fitted with a column-type crossbeam rather than an ordinary crossbeam.

Single-support plano-milling machines with a column-type crossbeam are suitable for use in repair shops and in one-off production workshops. They make it possible to machine large workpieces which cannot be machined on two-support machines of similar table width.

Plano-milling machines are considerably more rigid than column-and-knee milling machines, which means that they are capable of machining with greater precision.

The machining of a number of workpieces after a single setting of the machine considerably cuts down the auxiliary time. Reduction of the auxiliary time is achieved by equipping the machine with mechanisms to govern movements of various machine elements and for the setting-up of large diameter arbors and milling cutters, by mechanizing the locking of movable parts, increasing the speed of quick displacement of the table and other parts, and by making use of remote control.

A large number of special-purpose machine tools are constructed on the basis of universal plano-milling machines.

Planing machines

This group of machines includes the following basic types:

1. Longitudinal planing machines:
   single side
   double side
   edge-planing machines
   combined planing-milling-grinding machines
2. Shaping machines:
   with mechanical main drive
   with hydraulic main drive
   with electro-mechanical main drive
3. Slotting machines:
   general-purpose
   portable
4. Broaching machines for internal and external broaching.

Machine tools of the shaping-machine group are widely used in one-off and series production in various branches of machinery construction, and their productivity and precision of machining is constantly being increased through design improvements.

Shaping machines have a number of undeniable advantages which have won them an established place in the lists of equipment produced by machine tool manufacturers. The main advantages are: high productivity of labour when machining long narrow surfaces, simplicity and cheapness of the cutting tool and simplicity of sharpening, and the possibility of carrying out clean finishing shaping (instead of scraping and grinding) of workpieces, thus ensuring good results from the point of view of clean finish and precision of surface machining.

When only one workpiece of complicated profile has to be machined, the most economical method of machining is shaping rather than milling, which involves a complicated and expensive selection of milling cutters.

The use of combined shaping-milling-grinding machines when working on heavy frame parts of machines affords a highly economical combination of the operations of shaping, milling, boring and grinding, without need to move the workpiece.

A practice which is of great convenience to both the manufacturer and the consumer (particularly in the event of repair) - and followed by several machine tool manufacturers - is to unify to a considerable degree the parts used in longitudinal planing machines, plano-milling machines and longitudinal grinding machines, as this greatly reduces the number of different parts used in these machines.

Shaping machines can be equipped with copying carriages for the two and three-dimensional copying of workpieces of complicated profile.

The most important technical parameters of the shaping machines used in one-off and series production are the maximum travel of the slide, the dimensions of the working surfaces of the table, the distance from the bearing surface of the cutter to the frame, the number of to and fro movements of the slide per minute or the speed of the slide (for machines with hydraulic drive), and certain other features.

The technological capabilities of these machines can be considerably expanded by using universal rotating tables.

On general-purpose machine tools it is possible, by using the appropriate attachments, to carry out various operations such as machining of cylindrical and conical discs, radius planing, copying from a flat pattern, bending, thread-rolling and so forth.

It is advantageous to equip shaping machines not only with screw-operated machine clamps, but also with hydraulically operated clamps which can be switched into the hydraulic system without disturbing the normal operation of the machine tool.

Slotting machines are intended for cutting keyways and channels in cylindrical and conical apertures and also for machining flat and shaped surfaces in one-off and series production.

These machine tools can cut [illegible] and also carry out copying work when fitted with the relevant attachments. High-production broaching machines are manufactured for the broaching of [illegible] external broaching, and are used in series and mass production, [illegible], planing, milling, counter-boring, reaming, boring [illegible].

The high productivity and economic advantages [illegible] large number of cutting surfaces simultaneously brought into contact with the workpiece, the high precision and good finish of the broached surfaces, the relatively high durability of the broach and the possibility of using semi-skilled workers. However, the high cost of the broaching tool and the fact that the broaching machine can only be used efficiently on large batches of workpieces, limits its use to large-series and mass production.

Machine tools for abrasive working

This large group of machine tools includes:

Cylinder-and-cone grinding machines, centreless grinding and centreless lapping machines, internal grinding machines, surface grinding machines, rough grinding machines, slit grinding machines, thread and worm grinding machines, honing machines, polishing machines, sharpening machines, superfinishing machines, machines for lapping and external honing and specialised machines for the bearing, fuel, tool, turbine, watchmaking, instrument-making and other branches of industry.

The cylinder-and-cone grinding machines which are used in various sections of industry are intended for finishing operations requiring precision. The manufacturers of these machines are therefore paying great attention to increasing their rigidity and vibration resistance, to reducing heat deformations, to increasing precision of manufacture of the most important parts and to producing feed mechanisms which afford a smooth and gradual feed of the grinding head.

The automation of grinding head feed has become so widespread that it is found on almost all the machines now produced.

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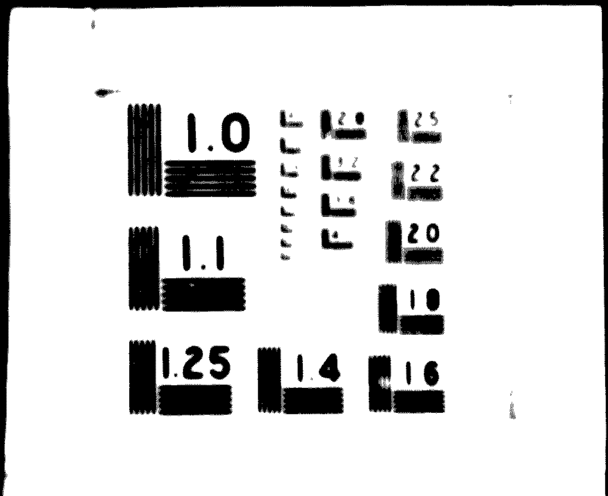


Mechanization of the cutter feed in general-purpose machine tools is also frequently met with.

The dimensions of the workpiece which is being ground are checked either manually or by pneumatic grips with an electric data transmission device.

If the head and tail stocks of the machine can be turned and it is fitted with equipment for internal grinding, both external and internal cylindrical and conical surfaces can be ground.

Certain machine tools have automated loading and unloading of the workpieces.

Centreless grinding machines can advantageously be used when grinding large batches of parts in large-series and mass production.

These machine tools are usually of one of two basic types:

1. Machines with a fixed supporting blade and movable grinding and driving heads;
2. Machines with a movable support blade and a movable driving head.

The advantage of the first layout is that it secures a high degree of vibration resistance because the fast-revolving spindle and abrasive heads are located in the main body, firmly fastened to the frame of the machine. The machine is designed in such a way that when the driving head block is moved along the inclined guides, the workpiece is pressed harder against the driving head and there is consequently better braking of the workpiece.

In machines of the second type, the line of displacement of the workpiece is constant and the grinding disc is moved up to the workpiece as the disc wears down. This makes it unnecessary to move the loading devices, and the driving head is more rigid because there are no intermediate carriers for the support blade.

Machine-tool manufacturers are producing centreless grinding machines with manual, semi-automatic and automatic control. Semi-automatic machines for incisive or longitudinal grinding have incision mechanisms, adjustments for wear of the grinding disc when grinding, and compensation for reduction of grinding disc diameter. Automatic machines specially set for the grinding of solid workpieces are produced on the basis of semi-automatic grinding machines. Modern universal internal grinding machines have quite a high degree of mechanization of the machine movement and automation of the controls, thus making it possible for them to carry out a semi-automatic grinding cycle when working on a batch of identical workpieces.

Universal internal grinding machines for the grinding of conical workpieces are provided with means for turning the workpiece head in the horizontal plane. It is advantageous if both the internal hole of a workpiece and the external end face perpendicular to the axis of the hole can be ground without reloading the workpiece in the machine, and this is made possible by an end-grinding attachment fitted to the workpiece head.

Both cylinder-and-cone grinding machines and internal grinding machines are usually also produced in higher-precision versions which give minimum dimensional deviations of not more than 0.5 microns for circularity and 1-2 microns for dimensional accuracy.

Various specialized types of machines are constructed on the basis of universal grinding machines, such as machines for grinding camshafts and crankshafts, workpieces which are large but not heavy (e.g. the rotors of jet engines), bearing rings and so forth.

Surface grinding machines are produced in various types and for various functions.

Machines which grind with the periphery of the grinding disc produce work of a high degree of dimensional precision and give a good finish to the ground surface. When the requirements for precision and quality of finish are not so high, grinding machines with a higher output which use the face of the grinding disc are employed.

There are four basic types of surface grinding machines:

1. Those with a rectangular table and a horizontal spindle for grinding with the periphery of the grinding disc;

2. Those with a rectangular table and a vertical spindle for grinding with the face of the grinding disc;

3. Those with a round table and a horizontal spindle for grinding with the periphery of the grinding disc;

4. Those with a round table and a vertical spindle for grinding with the face of the grinding disc.

Precision machines with a horizontal spindle and rectangular table are produced for tool shops. These machines are notable for their increased rigidity and for a number of design features which are necessary in order to attain high precision and good finish. The table and carriage of the machine are usually mounted on rolling guides.

High-output surface grinding machines designed for use in series production operations have a high-powered grinding head drive, a rectangular table and a horizontal or vertical spindle. In simplified versions, only the basic working movements are mechanized and the cycle is controlled by the operator manually.

On semi-automatic machines with constant automatic checking of the workpiece dimensions, the automatic machining cycle covers both the roughing and finishing grinding and the halting of grinding when the requisite dimensions have been attained.

The largest surface grinding machines are produced in portal form with a rectangular table. There are several different models of these machines, differing in the number and type of grinding heads fitted.

Machine tool manufacturers are also producing double-sided end-face grinding machines for the simultaneous grinding of the two end faces of parts such as discs, rings and rollers.

Rough grinding machines are used for cleaning up various rolled sections: e.g. round and square sections, slabs and tubes. The use of mechanised machine tools considerably increases labour productivity, eliminates heavy manual work and improves working conditions.

The mechanization of labour in roughing and finishing work is also achieved through the use of stationary, suspended and hand grinding machines.

Thread grinding machines are used in tool making for the production of screw-threaded measuring and cutting tools and high-precision threaded parts.

The thread grinding machines most frequently used in industry are those of universal type, which are used mainly for grinding cylindrical and conical screw-threads (on both external and internal surfaces), grinding precision screw-threads and worms, producing knurling rollers, and relieving screw taps and small-module hobbing cutters. In order to make the additional movements (when relieving, milling cones and so forth) which are necessary when machining tools of different types, universal thread grinding machines must be equipped with the appropriate mechanisms and attachments, with a consequent substantial increase in the complexity of their design.

Machine-tool manufacturers are producing specialized thread grinding machines for carrying out individual types of operations such as grinding threads of great length, grinding internal threads and so forth.

Ordinary grinding machines, which are indispensable both in the smallest workshop and in the production departments of great machinery-building factories, are produced in a wide range of types, varying from the simplest bench grinders to special automatic grinding machines.

The best type of grinding machine for use in the mechanical engineering workshops of small factories is that consisting of two abrasive discs mounted on the ends of the shaft of a suitably housed electric motor for manual sharpening and grinding operations. The abrasive discs are housed in casings connected to a dust removal plant, and a rotatable table on which cutting tools are rested for sharpening makes it possible to secure the desired geometry of the sharpened tool edge.

These machines are usually fitted with equipment for sharpening drills and for the dressing of the abrasive discs without the use of a diamond dressing device. They can also be fitted with buffing heads.

The diamond dressing and finishing of grinding discs, which is particularly necessary when a clean ground surface on the sharpened edge of a tool, rectilinearity and sharpness of the edges, and precision of the radius at the cutting point of a tool are required, must be carried out on grinding-wheel dressing machines specially equipped for this purpose, which sometimes take several grinding discs on one spindle.

The electrochemical sharpening of hard alloy tools is carried out by means of a grinding disc consisting of diamond particles in a metal binder, with a low-tension (6-12 volts) current passed between the diamond disc and the tool that is being sharpened, through an electrolyte which is continuously supplied to the grinding area.

The electrochemical sharpening of hard alloy tools is two to three times more productive than normal methods of sharpening.

Special electrochemical grinding machines are produced for this purpose.

Gear cutting machines

Gear cutting machines are divided into gear milling machines, gear shaping machines, gear planing machines and gear broaching machines, depending on the nature of the particular operation they perform.

The machines most widely used for producing cylindrical gear wheels in the machinery-construction industry are gear milling machines, which cut gear wheels with hobbing cutters, cutting discs and end milling cutters.

These machine tools are of high output and have been widely adopted in industry, as have the tools used on them.

Both the roughing and finishing machining of cylindrical gear wheels is carried out on gear milling machines.

The most widely adopted and easily readjusted gear milling machines for the small-series and series production of gear wheels are those which operate by means of a tool moving along the tooth that is being cut.

In large-series and mass production, it is more advantageous to use machine tools where the workpiece is moved along the cutting tool, as such machine tools do not take up much factory floor space, and when equipped with suitable automatic loading devices they are transformed into fully automatic machines. The disadvantage of these machine tools is the large amount of time and labour required for their readjustment.

Table 6 below gives some general technical parameters for widely used universal gear milling machines with vertically moving carriages. These parameters are an index to the machines' capabilities under normal working conditions.

Table 6

Parameters	Maximum diameter of gearwheels which can be machined						
	200-250	400-500	630-800	1250	1800-2000	2500-3200	5000
Maximum module size, mm	4	6-8	8-10	12	18-20	18-30	40
Number of revolutions per minute of milling cutter	45-450	40-310	40-310	32-200	8-100	10-60	10-60
Feed rate, per revolution of the workpiece, mm							
- axial	0.32-5.0	0.4-5	0.4-5	0.5-5.6	0.3-15	0.3-15	0.3-15
- radial	0.08-1.0	0.2-2	1.1-1.3	0.2-2.5	0.08-1.5	0.08-1.5	-
- tangential	0.16-2	0.15-3	0.15-3	0.08-3.8	0.08-15	0.08-1.5	-
Power of main electric driving motor, kW	5	7	7	10	14	25	25

In one-off and small series production it is economical to use not costly highly automated machine tools but simplified models on which the setting of the number of revolutions per minute, the milling cutter feed, the dividing mechanism drive and the differential mechanism is effected by changing gear wheels.

Gear milling machines must be operated in accordance with the instructions and directions delivered with each machine tool, and measuring instruments are essential in order to maintain and verify their accuracy. For this purpose levels, try squares, straightedges, measuring gauges, minimeters and autocollimators are usually sufficient.

Gear shaping machines have a lower output than gear milling machines, mainly because of the intermittent nature of the tooth-cutting process, but they are essential for cutting inside and outside blind splines and are therefore produced in large numbers.

At the present time, all gear shaping machines are semi-automatic and can be divided into the following categories:

1. Vertical machines operating with a cutter;
2. Vertical machines operating with a multi-cutter head;
3. Horizontal machines operating with chasing tools·
4. Vertical machines operating with a chasing tool.

Special models of these machine tools are also produced for machining racks.

On vertical machines operating with a cutter it is possible to machine gear wheels with a diameter of up to 3,000 mm, a tooth module of up to 12-15 mm and a tooth length of up to 200-275 mm. For machine tools of the remaining categories, except for the second, these gear-wheel parameters are almost double. The finishing machining of gear wheels is carried out by the process of gear shaving, which has been widely adopted in large-series and mass production branches of machinery construction, such as the automobile, tractor, aviation and other industries, in which the stability of the gear-making materials and thermal treatment of the workpieces make it possible to dispense with subsequent finishing operations after hardening. The minimal deformation which nevertheless occurs is provided for in advance by corresponding correction of the shaver.

In industrial production, the finishing machining of hardened gear wheels is usually carried out by gear grinding. On small-module (modules up to 1 mm) gear wheels, the whole cutting of the teeth is by grinding of the smooth workpiece.

Gear grinding is an expensive and not very productive process, and gear grinding machines require highly skilled operators. But the growing demand for precision gear wheels to run at high peripheral speeds is causing an increase in the use of the gear grinding method.

The general characteristics of five basic types of gear grinding machines, grouped according to principle of operation and field of utilisation, are given below.

I. Machines operating with conical abrasive heads by the rolling method

On these machines, the workpiece is given a slow rotary and forward rolling movement in contact with the conical edge of an abrasive disc, which moves quickly along the tooth.

Depending on the design of the machine tool, the sides of each tooth are ground either alternately or simultaneously. Indexing of the workpiece is effected at the end of each rolling stroke.

Machine tools which operate according to a preset automatic cycle, including correction of the grinding disc, are very easily readjusted by means of interchangeable gear wheels, and are used in both one-off and small series production.

II. Machines operating with a flat grinding head by the rolling method

In these machines, the rolling movement is achieved by an evolvent cam while the indexing movement is achieved by a special indexing disc. Only one side of the tooth profile is machined at a time.

These machine tools are not universal and their productivity is low, but due to their very short driving train they afford high precision and they are used in the toolmaking industry for grinding gear cutting tools, shavers and calibration gear wheels.

III. Machine tools operating with edge-cutting disc-type grinding heads by the rolling method

The special feature of these machine tools is that they can simultaneously grind both faces of a gear tooth, and as the workpiece is moved along the abrasive disc, teeth of considerable length can be cut. Because of the small area of contact, there is no local overheating of the teeth.

The machining of the teeth is of high accuracy, although less than on machines operating with a flat grinding head.

IV. Machines operating with a profiled grinding head by the profile copying method with non-continuous indexing

These machines have been improved in quite important respects in recent years, and the method of profile copying is becoming increasingly widespread. It is used at present for machining cylindrical straight-tooth and spiral internal and external gears.

The disadvantage of these machine tools is the high cost of dressing the profiled grinding head. Unless ordered with the machine tool, the necessary evolvent templates can only be made if the user has a toolmaking shop and skilled gauge makers available.

V. Machines operating with an abrasive worm by the rolling method with continuous indexing

These machine tools are used in large-series and series production, as they are four to ten times more productive than the other types of machines. This is due to the continuous nature of the machining process and the large cutting surface of the tool.

The latest models of these machines can grind gear wheels with barrel-shaped teeth.

The main types of machine tool for producing conical straight and spiral-tooth gear wheels are gear planing, gear milling and gear cutting machines, all of which operate with cutter heads, and gear grinding machines. Gear lapping, gear inspection, cold working and other auxiliary machine tools are also produced.

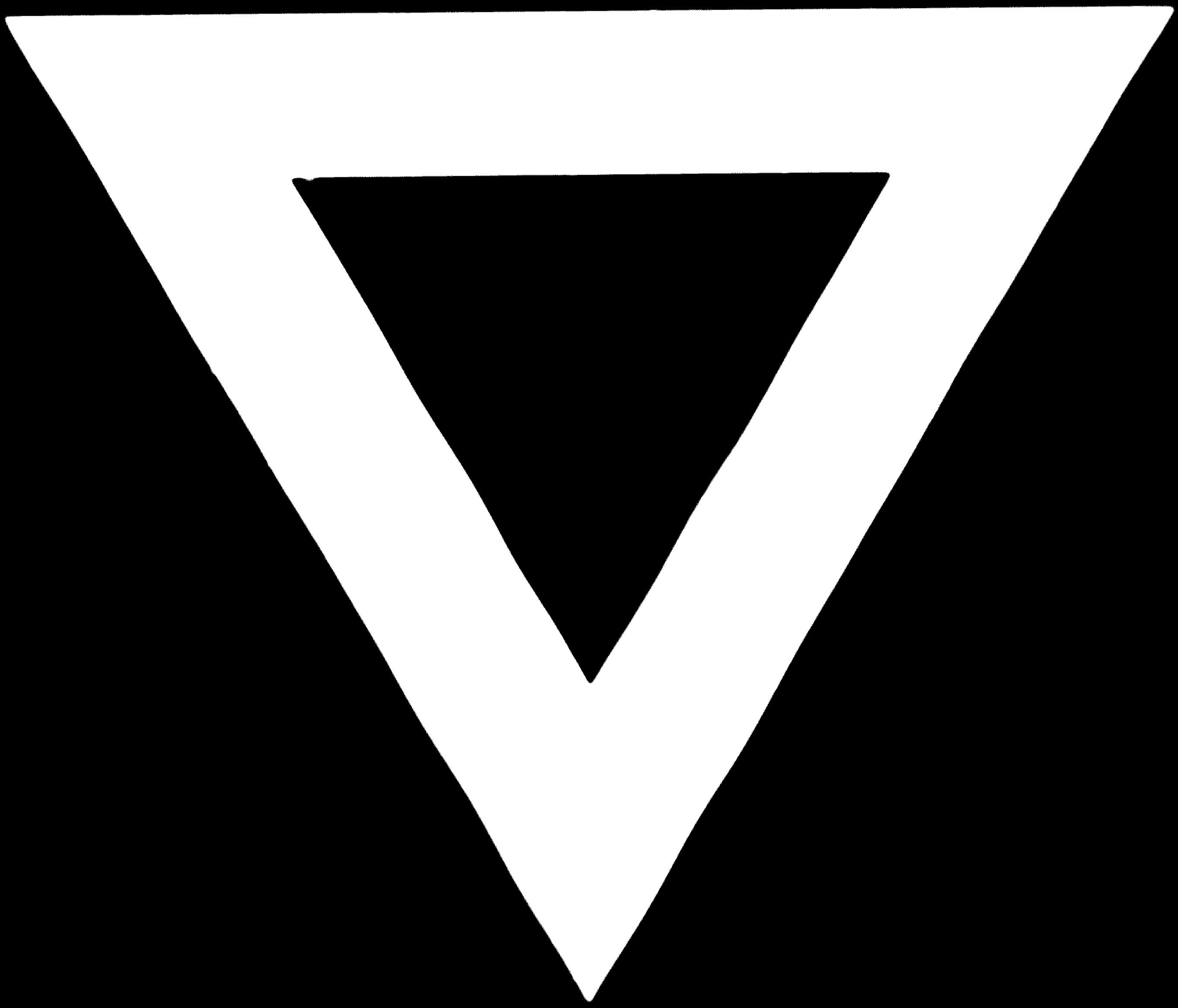
Because of the possibility of their universal utilization and the simplicity of the tool used, gear planing machines have come to be widely used for the one-off and series production of straight-toothed gear wheels. These machine tools are of low productivity, however, and the machining, for example, of a 40-tooth gear wheel with a 6 mm module takes at least thirty to forty minutes.

For this reason, higher-production gear milling machines are being more and more widely used in industry to produce straight-toothed conical gear wheels. As the setting up of these machine tools is more complicated than that of gear planing machines, and as the cost of the milling cutters is considerably higher than that of ordinary cutters, these machines are only used in large-series and mass production.

The good operating qualities (smoothness of running and durability) of spiral bevel gears, and the fact that a simple multi-cutter tool (cutting heads) can be used for machining them, have led to the creation and expansion of demand for gear cutting machines for machining spiral bevel gears.

Gear grinding is used to produce high-precision cylindrical and bevel gears from hardened workpieces.

In mass and large-series production, lapping is frequently used instead of gear grinding to produce precision gear wheels from press-hardened blanks. This increases productivity and lowers the cost of machining.



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