Ministry of Education and Science of Russian Federation
Federal State Autonomous Educational Institution of Higher Professional Education
“National Research Tomsk Polytechnic University”

APPROVED BY
director of
Institute of Cybernetics
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«___»_____________2016

Methodical instructions for performing laboratory works in « Technology of Mechanical Engineering» for foreign students trained at the International Education Institute

Tomsk 2016

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The methodical instructions for performing laboratory works have been submitted to the approval of the Faculty, Speciality Training Departments, the Institute of International Education and meets the curriculum requirements.

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Laboratory work №1
"Measurements with a micrometer and vernier measuring tools"

The purpose of work:

1. To make students acquainted with the equipment and methods of measurement of external and internal sizes.
2. To help students acquire elementary skills of experimental research work when carrying out laboratory work.
3. To study the basic operations of inspection of measuring tools.
4. To acquire skills of defining the metrological characteristics of measuring device.
5. To familiarize with the device and principle of measurement with vernier and micrometric measuring tools.
6. To estimate the accuracy of controlled parts and write the accordance designations in the drawing.

The equipment and materials:

1 Vernier calipers.
2. A vernier depth gage.
3. A vernier height gage.
4. A universal bevel protractor.
5. Micrometers.
6. Tubular inside micrometers.
7. Depth micrometers.
7. Gage blocks
8. Parts.

The order of work

1. Familiarize with the device and principle of measurement with vernier measuring tools.
2. Define the metrological characteristics of a given tool and write down its conditional designation.
3. Define the validity of a given tool on a gleam between the lips, concurrence of zero strokes vernier and the basic scale.
4. Define a measurement error of the device with the help of gage blocks (end measures of length.)
5. Measure the given part and define its validity.
6. Familiarize with the device and principle of measurement of micrometric tools.
7. Define the metrological characteristics of a given tool (micrometer) and write down its conditional designation.
8. Define the validity of a given tool on a gleam between the spindle and anvil, concurrence of the vernier zero strokes and the basic scale.
9. Define a measurement error of the device with the help of gage blocks (end measures of length.)
10. Measure the given part and define its validity.

11. Draw a sketch of a part and put down its valid dimensions.

1. Vernier measuring tools

A vernier is a short rule or scale that is mounted on a measuring instrument so that its graduations subdivide the divisions on the main scale. Verniers increase the degree of precision which can be obtained from both linear and angular measuring tools. The French mathematican, Pierre Vernier, invented the vernier scale in about 1630 A.D.

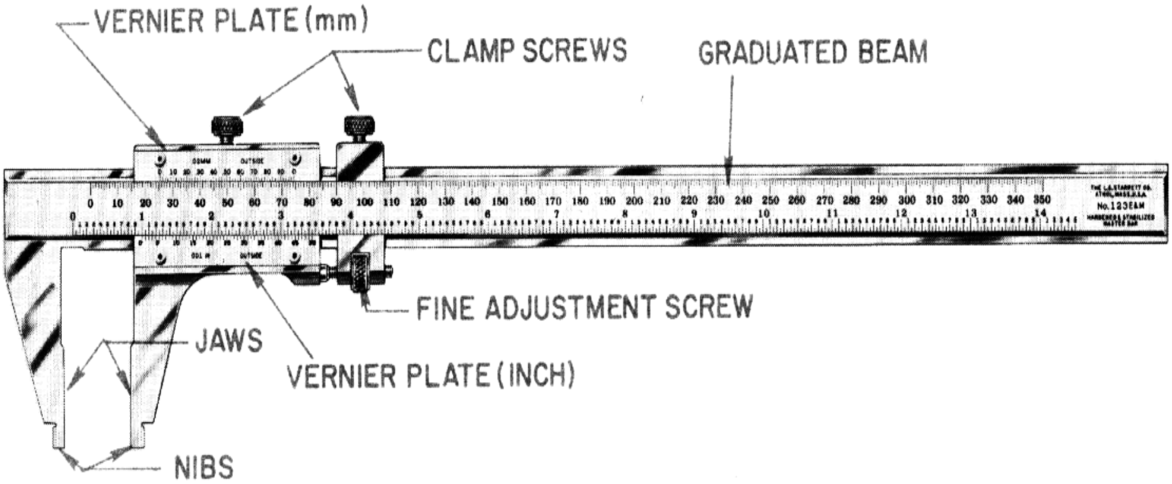


Fig. 1. A vernier caliper.

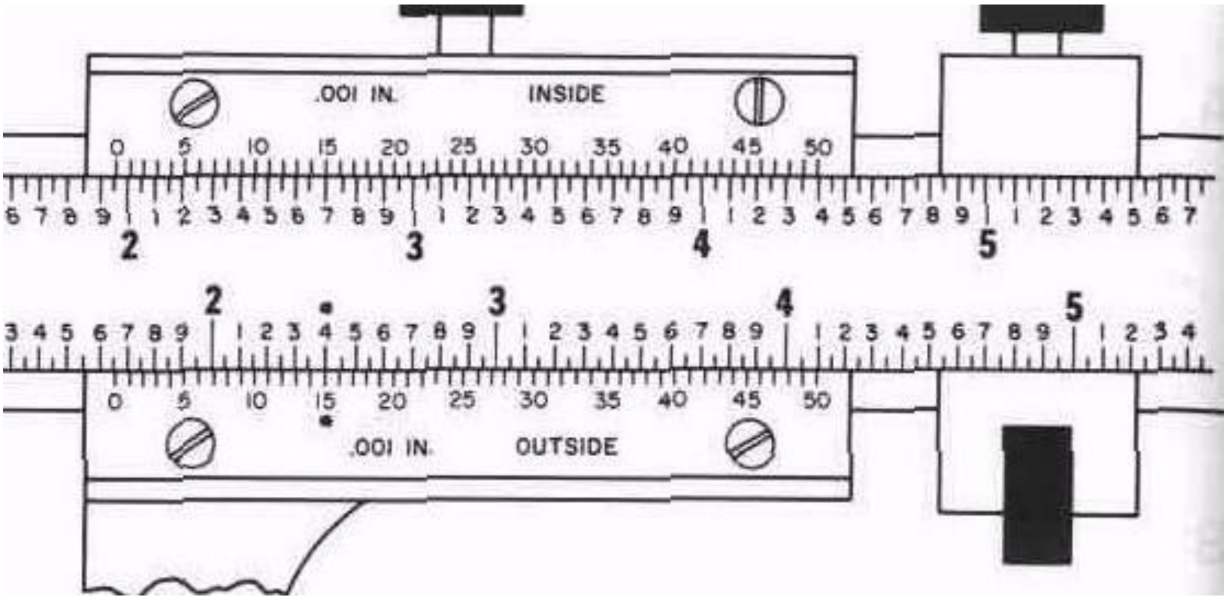
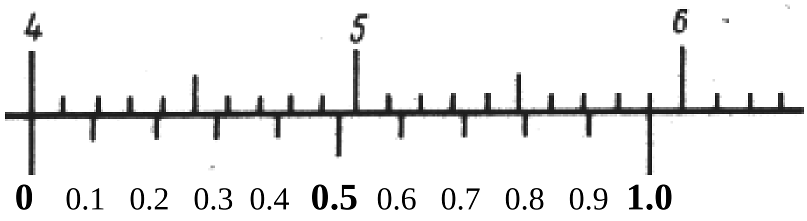


Fig. 2. A 50-division inch vernier reading of 1.665".

A **vernier caliper** is made up of a graduated beam with a fixed measuring jaw, a movable jaw which carries a vernier scale and a mechanism for making fine adjustments, fig. 1. Vernier calipers are capable of making both outside and inside measurements. In addition, some are also provided with a depth measuring rod. When inside measurements are made the size is read on the single scale for both outside and inside measurements but it is necessary to add a number which is marked on the jaw. The reading in fig. 2 is explained as follows:

1. The zero on the vernier plate is between the 1" and 2" marks on the beam, making 1.000".
2. The zero on the vernier plate has passed the 6 on the beam, indicating 6/10ths or 0.600".
3. The zero on the vernier plate has passed the midpoint division between the 6th and 7th marks, adding 1/20th"or 0.050".
4. The 15th line on the vernier matches a line on the beam, adding 0.015"
5. The total reading is 1.665".

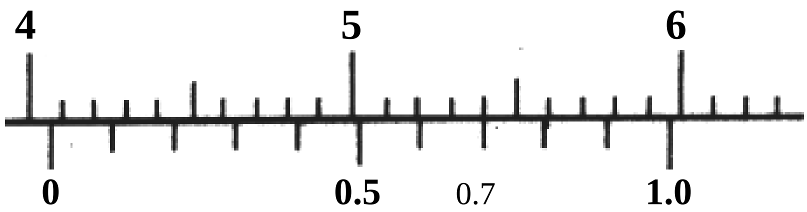
Scale



responsibility of vernier scale r = 0.1 mm

a

Scale



b

Fig. 3. Reading of scale and vernier (vernier caliper with 0.1 mm division: a) size 40 mm; b) size 40.7 mm.

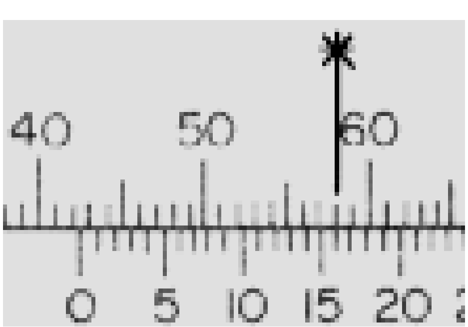


Fig. 4. Reading of 42.16 mm on metric vernier scale (0.01 mm division).

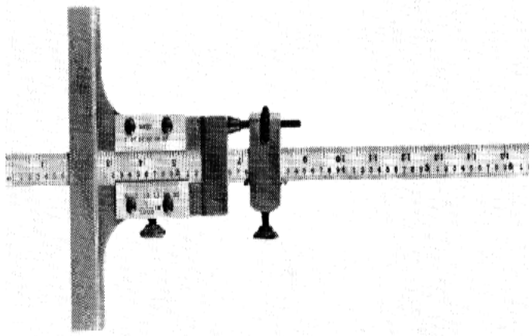


Fig. 5. A vernier depth gage.

Many kinds and sizes of vernier calipers have been developed for various measuring applications. The following are the principal kinds: vernier depth gage (fig. 5), vernier height gage (fig. 7), vernier gear tooth caliper.

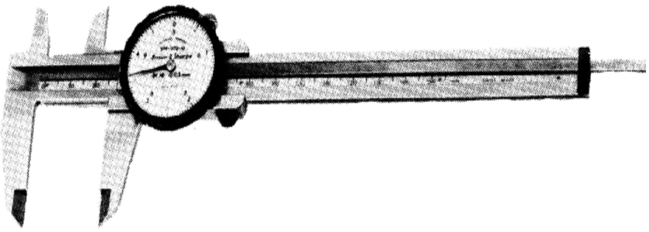


Fig. 6. A vernier caliper with a dial indicator (0.02 mm division reading) and a depth measuring rod.

A **universal bevel protractor** equipped with a vernier, fig. 8, measures angles accurately to 5 minutes or one-twelfth of a degree. This tool is also called a **vernier protractor.** It may be used to lay out, measure, or check angles. A 150 or 300 mm blade may be inserted in the graduated dial and locked in position with the blade clamp nut. The blade and dial are swiveled to the angle desired, and the dial is locked with the dial clamp nut. An acute-angle attachment is provided for use in measuring angles of less than 90°.

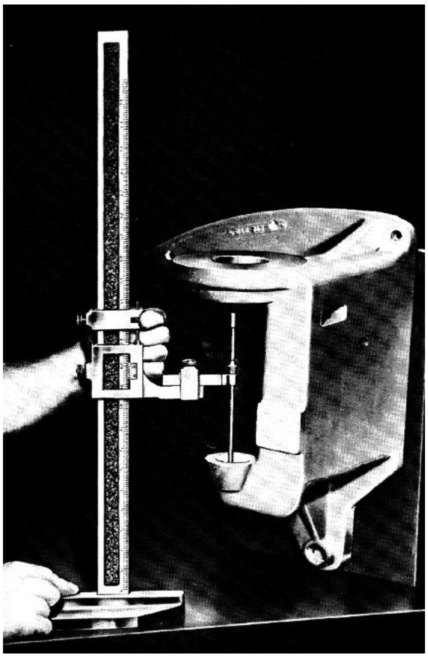


Fig. 7. A vernier height gage.

The protractor dial is graduated 360°, reading in whole degrees from 0 to 90, 90 to 0, 0 to 90, and 90 to 0. Each 10 degrees is numbered, and a long graduation divides each 5 degrees. The vernier plate is graduated with 12 spaces. Thus, each line here represents 5 minutes or one-twelfth of a degree. Every third line on the vernier plate is numbered to represent 15, 30, 45, and 60 minutes. Both the protractor dial and the vernier plate have numbers in both directions from zero.

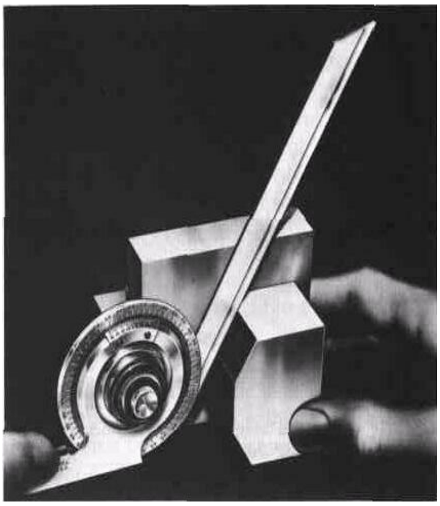


Fig. 8. A universal bevel protractor.

When angles are read in whole degrees, the zero line on the vernier plate coincides with a graduation line on the protractor dial. Also, the graduation for 60 minutes will coincide exactly with a graduation on the dial. When angles are read which are not in whole degrees, the following procedure is used. Note how many degrees can be read from the zero line on the dial up to the zero line on the plate. Then, reading in the **same direction** (and this is important) note the number of minutes indicated by the line on the vernier which coincides exactly with a line on the dial. Add this amount to the number of whole degrees.

2. Micrometric measuring tools

Micrometers are the precision measuring tools most commonly used by machinists. They are available in a variety of types and sizes, but the most common is **the outside micrometer caliper**. Fig. 9 shows a 0-25 mm outside micrometer of traditional design. Several micrometers of more recent design include the following:

1. Indicating micrometer, which can also be used as a comparator for quickly checking parts in quantity;
2. Direct reading micrometer, which provides a numerical display of the micrometer reading;
3. Dual reading micrometer, which reads both in metric and in English measurement;
4. All electronic micrometer, which has a motorized spindle and electronic digital readout.

A micrometer often is called a «mike». Plain metric micrometers measure accurately to one-hundredth of a millimeter (0.01 mm). Some metric micrometers are equipped with a vernier which makes it possible to measure accurately to one-thousandth of a millimeter (0.001 mm).

The parts of a traditional micrometer are shown in fig. 9. The principal parts are the **frame,** the **anvil**, the **spindle** with a precision screw thread, the **sleeve** which is also called a **barrel or hub,** and the **thimble.**

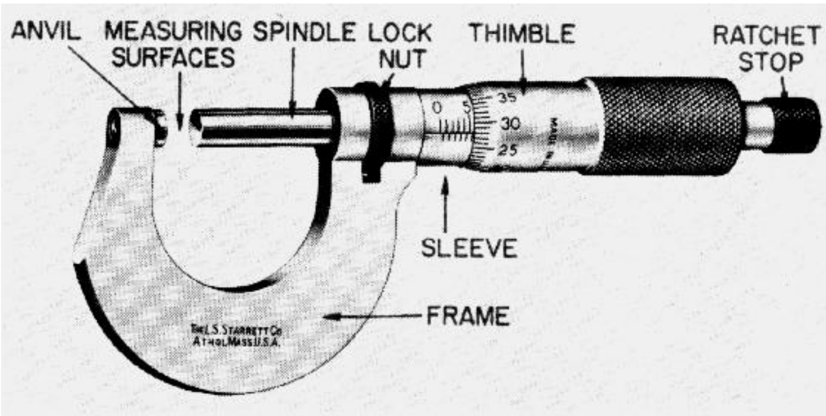


Fig. 9. Principle micrometer parts

The **ratchet** and the **lock nut** are convenient accessories which are available on some micrometers. With the use of the ratchet, a consistent pressure can be applied on the spindle when measurement is made, regardless of who uses the tool. A consistent pressure is important in making accurate measurements. Without the ratchet, one must develop the right feel for accurate measurement. The lock nut locks the spindle in position after measurements are made.

Many kinds and sizes of micrometers have been developed for various measuring applications. The following are the principal kinds:

Outside micrometers, also called **micrometer calipers,** fig. 9, are used for measuring outside diameters or thickness. Outside micrometers are available in various sizes which are limited to 25 mm measuring ranges, such as 0 - 25 mm , 25

- 50 mm, and so on. Large micrometers are available for measuring within various 25 mm ranges. Some of them may be used for measurements simply by changing and installing the appropriate anvil. Micrometers are graduated in one-hundredths of a millimeter (0.01 mm). The pitch of the spindle screw is 0.5 mm. Thus, one revolution of the thimble moves the spindle 0.5 mm toward or away from the anvil.

The reading line on the sleeve is graduated in millimeters. Every fifth millimeter is numbered. Each millimeter is also divided in half (0.5 mm). It requires two revolutions of the thimble to move the spindle 1.0 mm.

The beveled edge of the thimble is graduated in 50 divisions. Every fifth line (from 0 to 50, although 50-th division is numbered by 0) is numbered. Thus, each thimble graduation equals 1/50 of 0.5 mm, or 0.01 mm. Two thimble graduations equal 0.02 mm, etc.

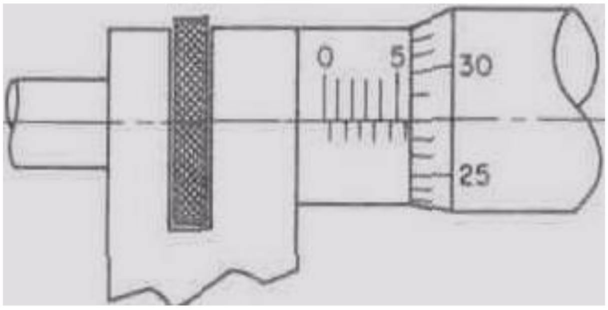


Fig. 10. Micrometer reading of 5.78 mm.

To read the micrometer, count the number of millimeters and half-millimeters visible on the sleeve. Add these to the number of hundredths of a millimeter indicated by the thimble graduation that coincides with the reading line on the sleeve. The metric micrometer reading of 5.78 mm illustrated in fig. 10, is obtained as follows:

1. Upper sleeve reading (whole millimeters)	5.00 mm
2. Lower sleeve reading (half millimeters)	0.50 mm
3. Thimble reading (hundredths of a millimeter)	0.28 mm
Total Reading	5.78 mm

Inside micrometers are used for measuring inside diameters, parallel surfaces, or other inside dimensions. There are several types and sizes of inside micrometers available. A small inside micrometer caliper may be used to measure within the range from 5 mm to 25 mm. Fig. 11 shows a **tubular inside micrometer.** It may be used for measuring inside diameters from 40 mm to 300 mm, in range increments of 13 mm. Measuring rods are added to either or both ends of the micrometer head to increase its range. A tubular inside micrometer can be used for measuring large diameters. **Mike hole gages** are used for accurate measuring

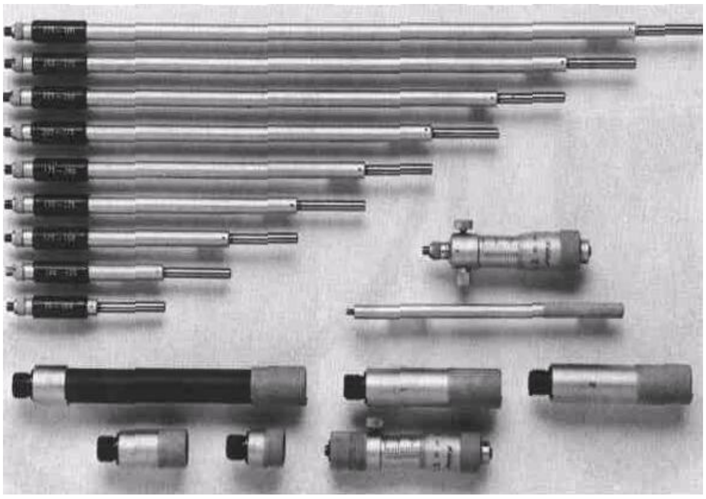


Fig. 11. Tubular inside micrometer.

the diameter of relatively small holes. They are available in various size ranges from 6 mm to 200 mm. Setting rings are available in various sizes for testing and setting the accuracy of inside micrometers.

Fig. 12. Measuring depth of a shoulder with a depth micrometer.

Depth micrometers are used for measuring the depth of holes, grooves, shoulders, and projections, as shown in fig. 12. The measuring range for depth micrometers can be increased in multiples of 25 mm, as desired, by installing interchangeable measuring rods.

Thread micrometers are used to measure the pitch diameter of screw threads (fig. 13).

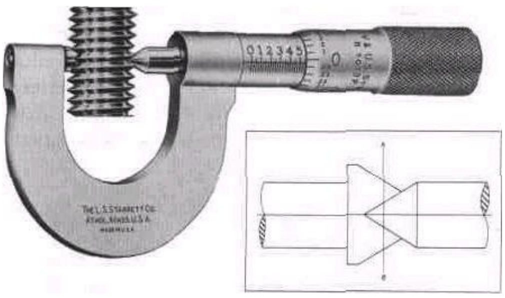


Fig. 13. Thread micrometer.

Vernier metric micrometers and **dial indicating micrometers** (fig. 14) are designed for measuring to 0.002 mm or even 0.001 mm. The vernier scale is placed on the sleeve above the usual graduations, but note that the millimeter and half millimeter graduations are both marked on the lower part of the sleeve.

This allows the vernier to be read without having to twist the micrometer.

It is necessary to check measuring instrument before working. Gage blocks (or known as Jo-blocks, invented by Johanson) are used for this purpose (fig. 15).

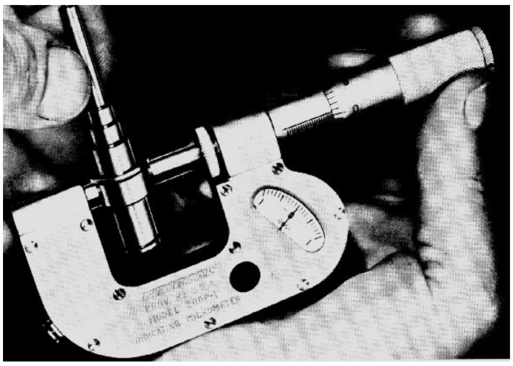


Fig. 14. Measuring diameter of a shaft with a dial indicating micrometer.

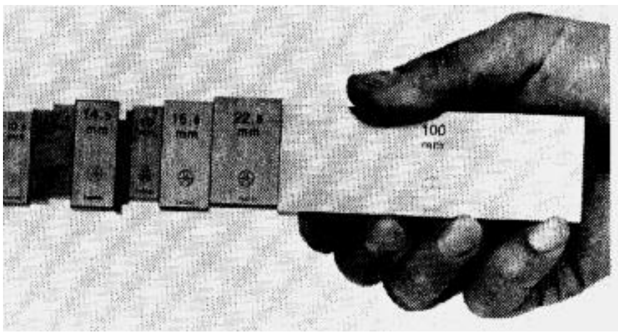


Fig. 15. Gage blocks wrung together.

3. Metrological characteristics of measuring tools

1. ***Division reading*** or ***responsibility*** of a scale. It can be 0.1, 0.05, 0.02 mm (vernier calipers), 0.01 mm (micrometers), 0.005 mm (thimble of toolmaker's microscope), 0.002, 0.001 mm (dial indicating micrometers), 0.0005 mm (opticators), etc.
2. ***Range of the scale***. It can be 0-160, 0-180, 0-250, 0-320, 320-640 mm (vernier calipers), 0-25, 25-50, 50-75, etc, mm (micrometers, fly-wheels of toolmaker's microscope), ±0.015, ±0.030, ±0.60, ±0.100 mm (dial indicating micrometers, optimeters, opticators), etc.
3. ***Whole measuring range of measuring tool***. It can be 0-160, 0-180, 0-250, 0-320, 320-640 mm (vernier calipers), 0-25, 25-50, 50-75, etc, mm (micrometers, dial indicating micrometers), 0-50 or 0-150 mm (toolmaker's microscope), 0-250 mm (optimeters, opticators), etc.
4. ***Measuring range of measuring tool with measuring rods*** or ***inserts.*** For example, for tubular inside micrometer 50-65 mm, 65-80 mm, etc.
5. ***Error of measurement***. Generally this error equals ± ***of division reading,*** but it has to be checked during the attestation and have different errors depending on the length of measuring movement (than it more than may more error).
6. ***Measuring load.*** It can be not fixing (vernier calipers, although it is not expensive and generally does not exceed 200-300 grams), 100 -150 grams (micrometers), 50-100 grams (dial indicating micrometers, optimeters, opticators), etc.

4. Order of performing work

1. Write down the designation of a given measuring tool (vernier calipers).
2. Write down the metrological characteristics of the given measuring tools.
3. Check measuring tools looking at the light (check the out of clearance between the jaws or anvil and the spindle). Write down the conclusion.
4. Check the adjustment of measuring tools (0 line of the vernier scale has to coincide with 0 line of the main scale). Write down the conclusion.
5. Check measuring tools with gage blocks (the main scale and separately the vernier scale). Write down the conclusion.
6. Repeat items 1 - 5 for the micrometer.
7. Measure a part with the vernier caliper and write down the measured dimensions in the design drawing of the part.
8. Measure 1 -2 dimensions of detail with the micrometer and write down the measured dimensions in the design drawing of the part (matching it with a symbol *).

9. Compare the measurements with the vernier caliper and micrometer. Write down the conclusion (the difference should not exceed 0.1 mm).

Laboratory work №2
"Measurements with dial indicating instruments"

The purpose of work:

1. To make students acquainted with the equipment and methods of measurement of external and internal sizes.
2. To help students acquire elementary skills of experimental research work when carrying out laboratory work.
3. To study the basic operations of inspection of measuring instruments.
4. To acquire skills of defining the metrological characteristics of measuring device.
5. To familiarize with the device and principle of measurement with dial indicator, a dial indicating hole gage and dial indicating snap gage.
6. To estimate the accuracy of controlled parts and write the accordance designations in the drawing.

The equipment and materials:

1. Vernier caliper.
2. Dial indicator.
3. Dial indicating hole gage.
4. Dial indicating snap gage.
5. Micrometer.
6. Dial indicating depth gage.
7. Gage blocks.
8. Universal dial indicator set.
9. Parts.

The measuring head and devices on their basis (indicators and display devices). The basis of these devices is the gear transfers. The increase in the measuring movement occurs at the expense of the large transfer relation. The readout is made on a dial with an pointer. The price of division in most cases is 0.01 mm, but the indicators with the price of division 0.001 mm are also used. A range of the accurate indicators on a scale is no more than 1 mm, that requires exact adjustment of the measured size. Usually indicators with the range of measurements on a scale 10 mm are used; seldom - 2 mm, 5 mm, 25 mm. The last parameter is used in a conditional designation: IH-10 - ***indicator***

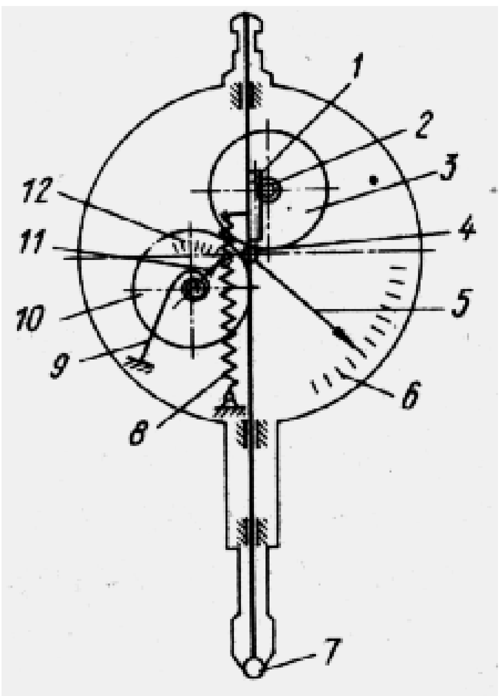


Fig. 1. Indicator of an hour type.

of an ***hour*** type (with gears) with a limit of measurement on a scale of 10 mm.

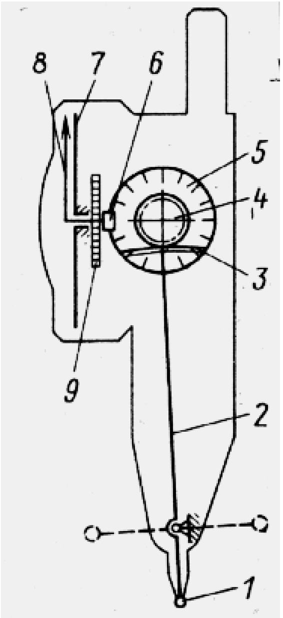


Fig. 2. The lever-gear indicator.

The scheme of the indicator (fig. 1) consists of rack 1, which is cut on a measuring rod. The rack is hooked with pinion 2 (a gear wheel with a small module and a small teeth number). There is gear wheel 3 with a large diameter on one axis with pinion 2. It is hooked with pinion 4 on whose axis basic pointer 5 is mounted. With the help of the pointer on the basic (main) scale 6 moving of measuring tip 7 is counted. Additional pointer 11 on the axis of auxiliary wheel 10, hooked with pinion 2, serves for readout of the revolution number of the basic pointer on a small scale 12. Spring 8 creates measuring effort, and spiral spring 9 eliminates backlashes (clearances) in the gear transfer.

The lever-gear indicators (fig. 2) are used basically for measurement of face palpation. Gear sector 3 rotates gear wheel 4 which transmits measuring moving through gear wheels 5 and 6 to pointer 8. Then more the difference between shoulders 1 (with measuring tip 1) and 2 of the lever the more is the sensitivity.

Dial Indicating Instruments

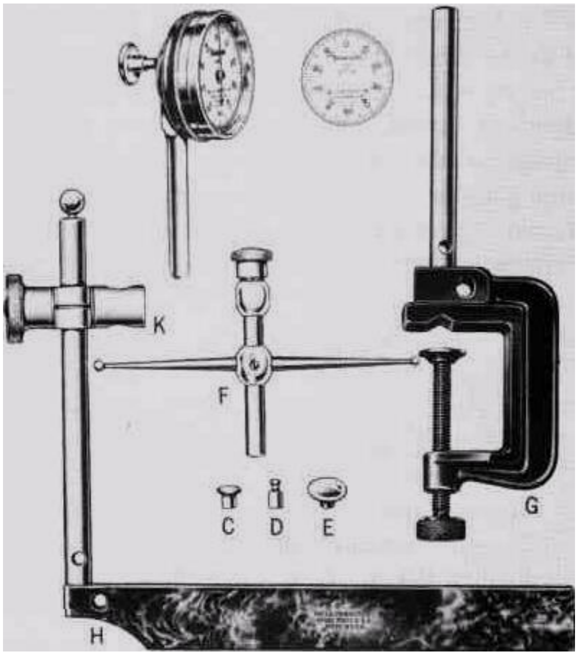


Fig. 3. Universal dial indicator set.
C, D and E are the contact points; F is the hole attachment; G- the clamp; H- the tool post holder; K-the sleeve.

Universal dial indicator sets are used widely. With the accessories, fig. 3, provided in this set, the dial indicator may be mounted on a surface gage for use on a surface plate or on a machine table. It may be mounted in the tool post of a lathe. It is particularly useful for aligning work in a four-jaw chuck, as in fig. 4, where it is being used with a hole attachment. It is also provided with a clamp so that it may be attached wherever needed for special applications.

A full range of accessories permits dial indicators to be held in surface gages, vernier height gages, and in lathe tool posts. With the aid of a ***magnetic base***, the universal dial test indicator can be quickly attached to any machine. It can also be held in a drill chuck or collet in a jig borer or vertical milling machine for use in checking alignment of vises, fixtures, or workpieces.

Numerous special gages are equipped with dial indicators. These gages are used widely for determining whether parts are within required size limits.

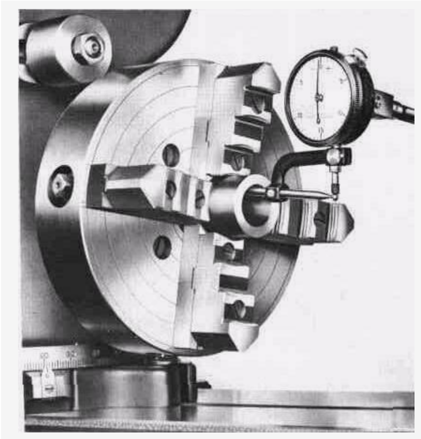


Fig. 4. Hole attachment permits accurate internal tests with dial indicator.

Dial indicating depth gages, fig. 5, are used for gauging or testing the depth of holes, slots, shoulders, recesses, and keyways. Extension points increase the measurement size, measuring depths at which the gage may be used.

Dial indicating hole gages, fig. 6, are used to gauge or test holes for size, taper, out-of-roundness, or other irregular conditions. They are available in a wide range of sizes.

Dial indicating snap gages are used for gauging diameters of parts to determine whether they are within the size limits specified. In use, the gage is snapped over the diameter of the part being gauged. Snap gages are efficient for checking parts which are produced in large numbers, and they are available in a wide range of sizes. Each gage may be used for measuring within a 25 mm range, such as 0-25 mm, 25-50 mm, etc. Size is set by adjusting the frame itself with the knurled wheel near the indicator. The gage may be used at an inspection bench where it can be mounted in a bench stand or right at the machine.

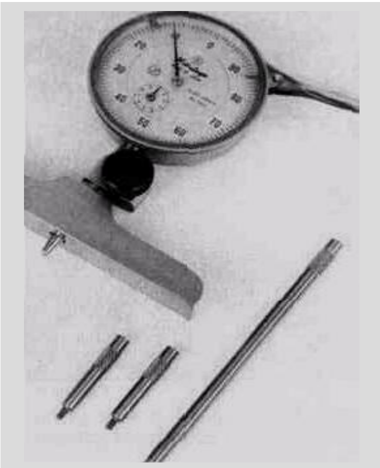


Fig. 5. Dial indicating depth gage with extension points.

A retractable contact snap gage is shown in fig. 7. The contactor point is opened with a button located conveniently for thumb operation. This type of gage is available in sizes which gauge, within certain ranges, (0-50, 50-100, 100-150, etc. mm).

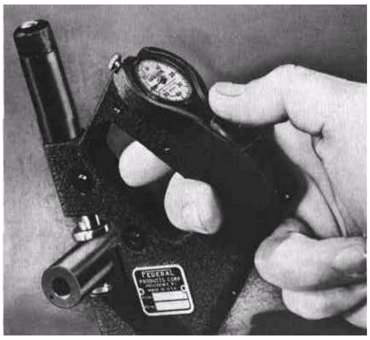


Fig. 7. Retractable contact snap gage.

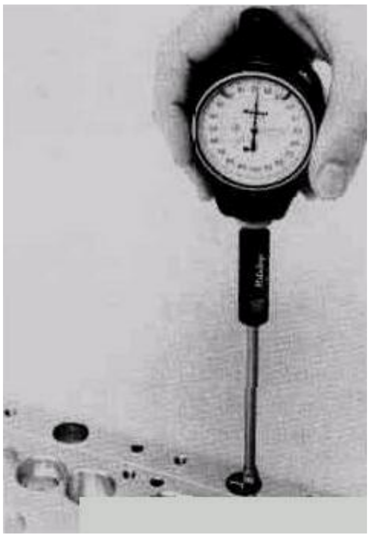


Fig.6. Dial indicating hole gage.

Dial indicating caliper gages, fig. 8, have revolution counters which make it possible to measure directly through their complete range of 75 mm. Calipers of this type are available with 0.02 mm graduations.

Setting discs and setting rings are used for checking and setting indicating caliper gages, snap gages, hole gages, comparators, and other types of gages. Setting discs and rings are available in many sizes.

Gage blocks (fig. 11) with holders and parallel plates are used for adjustment indicating gages on the determined size.

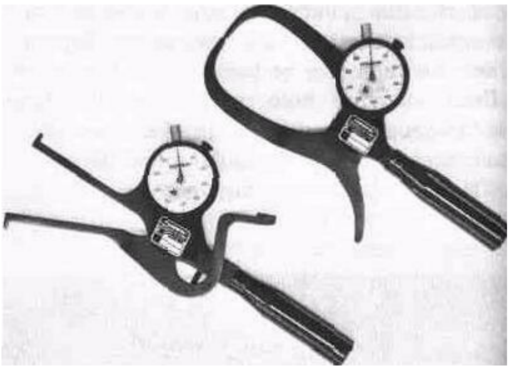


Fig. 8. Dial indicating caliper gages.

With the help of the indicator mounted on the post tool holder, it is possible to measure the size of a detail by an absolute and relative method, to measure errors of the form (deviation from roundness, straightforwardness etc.), error of an arrangement of surfaces (deviation from parallelism, perpendicular, etc.), total errors of the form and arrangement of surfaces: face and radial palpation (fig. 4).

All methods of measurements can be divided into 2 groups: the methods of absolute measurements and methods of relative measurements.

When we deal with **the method of absolute measurements** we obtain a dimension at once, reading the scale. For example, when we use a ruler, vernier caliper, micrometer. This method is available when we measure a small part with a dial indicator as shown in fig. 9, A.

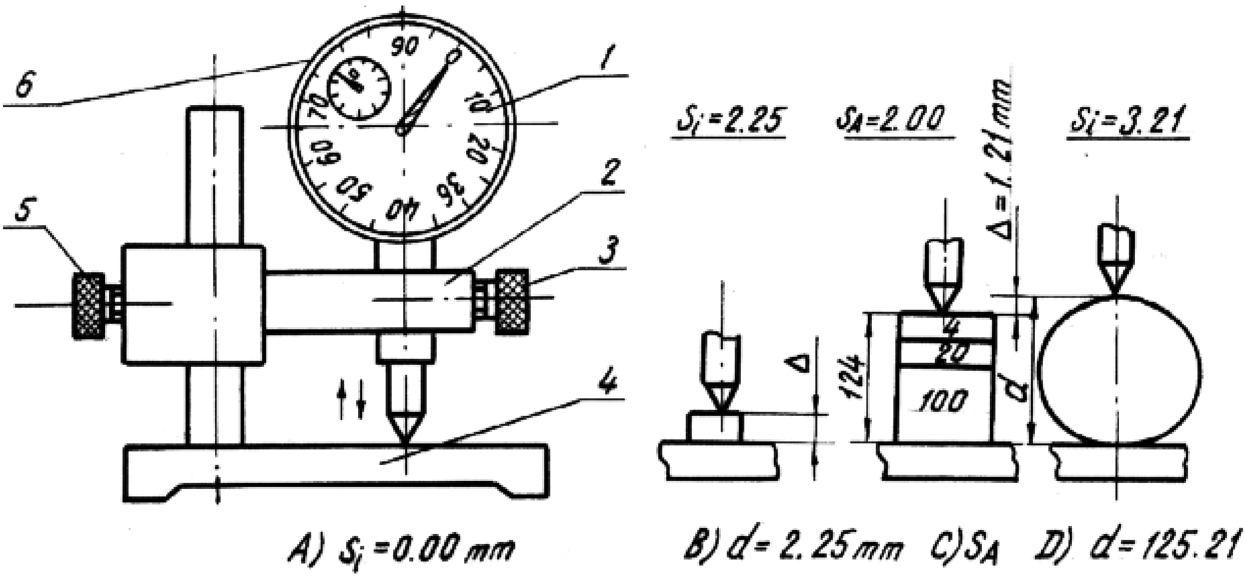


Fig. 9. Measuring a part with a dial indicator.

First of all, we must lower sleeve 2 together with indicator 6 in order to touch part-table 4 (further we shall call it the table) and indicator hands (pointers) must turn a little. It is better for us if the short hand is set against a stroke under the number 0 (zero). After that we have to fasten the sleeve. In order to make reading easier, we have to turn main face 1 of the indicator until the stroke of 0 is set against the long hand. We have adjusted the instrument, and after that we must not turn the face of the indicator. Our reading is 0.00 mm.

In order to measure a part, we must carefully lift the spindle and place our part on the table. Then we lower the spindle until it touches the surface of the part. We are reading the result. For example: the short hand shows 2, and the long hand shows 25. The dimension is 2.25 mm (fig. 9, B).

However, we can't use this method when the dimension of a part is larger than the range of an indicator. Then we can use **the method of relative measurements**.

First of all, we must know the approximate dimension of a part in order to adjust the instrument. We measure a part with the help of a simple instrument, such as a ruler or a vernier caliper. For example, our dimension is about 124 mm.

The second, we take gage blocks and compose the block (***GB***) 124 mm, using blocks 100, 20 and 4 mm. It is necessary to compose the block attentively, looking at the working polished sides of the blocks: they must contact each other. Before adjusting the blocks it is necessary to clean their working sides with alcohol.

The third, we place the composed block on the table and lower the sleeve, repeating adjusting as we have said before. However, it is better for us to adjust the indicator short hand not against 0, but against 1 or 2 mm in order that the reading should be possible if the dimension of a part proves to be less than we thought. For example, we have adjusted the indicator for 2.00 mm ($\mathbf{S_A}$ = 2.00 mm) when we placed the block of 124 mm (fig. 9, C).

The fourth: we replace the part on the table, lower the spindle and look at the face. For example, indicator shows 3.21 mm ($\mathbf{S_M}$ = 3.21 mm) (fig. 10, D).

The fifth, we define the relative transference: $\mathbf{\Delta_R} = \mathbf{S_M} - \mathbf{S_A} = 3.21 - 2.00 =$
$= +1.21$mm.

The sixth , we obtain the general dimension : $\mathbf{d} = \boldsymbol{GB} + \mathbf{\Delta_R} = 124+(+1.21) =$
$= 125.21$ mm.

This method is called «Method of relative measurements» as the measurement is made relatively to the block surface.

The ***advantages*** of this method are:

1. Higher accuracy, especially with small relative transference as the errors of the measuring tool will not be accumulated.
2. Short time required for the inspection process.

The ***disadvantages*** are:

1. Necessity of adjustment and measurements of only a definite adjusted size.
2. A long time of adjustment.

Inspector use ***all indicating gages*** with the help of the method of relative measurements.

Various devices on the basis of indicators widely are used such as dial indicating hole gages (fig. 6), indicating snap gage (fig. 11), tangent teeth meters, etc. In some of them (for example, in a normal meter) the sensitivity of the device increases at the expense of the difference of the levers shoulders (1:2). In this case, it is necessary to use such indicators which have the accuracy of manufacturing transmitting elements corresponding to an increase of sensitivity. In such indicators it is underlined: the responsibility 0.005 mm with the lever 1:2.

In most cases in display devices a relative method of measurements is used. All indicators and devices on their basis are periodically checked. Also the results of these checks within different ranges are shown in the certificate.

The basic advantages of indicators and devices on their basis:

1. Compactness.
2. Convenience of readout on a dial (the divisions are large, they are easily read).
3. The high speed of the control of an error of the form (it is not necessary constantly to twist a ratchet, as in a micrometer).
4. The possibility of measurement of the size and error of the form even at a large depth of an aperture (for indicator hole gages).

The ***disadvantages*** are:

1. The adjustment of the device is obligatory. Then closer adjustment size to measured size, the more the accurate are the measurements.
2. A rather narrow range of the indications on a scale. The readjustment of the device requires a lot of time, that is why an indicator device is required for each step or size for measurement of diameters of the step shaft or cartridge.

Gage blocks (fig. 10) are recognized throughout the world as a practical **reference standard** for measuring length. They are used in precision measurement laboratories, inspection departments, toolrooms, and machine shops for calibrating and setting many types of inspection gages, measuring tools, and measuring instruments. Gage blocks, therefore, are the connecting link between the national standard of measurement and measurement in the shop.

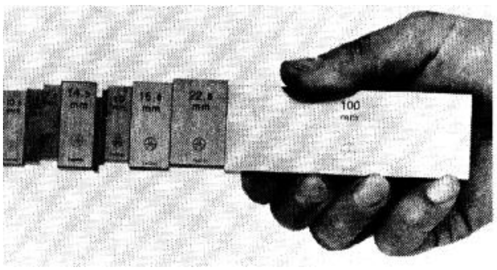


Fig. 10. Gage blocks wrung together set.

Manufacturers produce gage blocks in relation to master gage blocks which must be accurate to plus or minus 0.05 microns (0.05 μm). In many cases, their master gage blocks are accurate to within plus or minus 0.025 microns. These master gage blocks are checked periodically for accuracy with an **interferometer.** This instrument measures gage blocks in units of light wave length to within a fraction of the required tolerance. (Light wave length is not significantly affected by changes in temperature and atmospheric conditions.)

Gage blocks may be used together to make up various gage block combinations of greater length (fig. 10). When gage blocks are properly combined, they are said to be **wrung** together. Their surfaces are so flat and smooth that when properly wrung, they stick together as though magnetized.

Gage blocks normally are classified according to three accuracy classifications: Class 1 (formerly AA), Class 2 (formerly A+), and Class 3 (a blend of former A and B).

Some manufacturers produce gage blocks with the special classification, **laboratory master gage blocks,** to tolerances of half that for Class 1 blocks. These gage blocks, as well as regular **master** gage blocks (Class 1), are intended for special purposes in temperature-controlled gauging and measurement laboratories. They are used for experimental work, research work, and as grand master gages for measurement and inspection of other gages.

Class 2 gage blocks often are called **inspection gage blocks.** They are used primarily for inspection of finished parts and for inspecting and setting working gages. They also may be used as masters in inspection departments and toolrooms.

Class 3 gage blocks often are called **working gage blocks.** They are used for many applications requiring accurate measurement throughout the shop. They are used on surface plates for accurate layout, on machines for setting cutting tools accurately, and for ordinary inspection work.

Gage blocks are available in **sets** or as **individual blocks**. Sets are available with from 5 to more than 100 gage blocks. ***A commonly used standard set of 48 metric gage blocks consists of***:

2 blocks: 1.000, 1.005 mm;
9 blocks: 1.001 through 1.009 by 0.001 mm;
9 blocks: 1.01 through 1.09 by 0.01 mm;
9 blocks: 1.1 through 1.9 by 0.1 mm;
9 blocks: 1 through 9 by 1 mm;
10 blocks: 10 through 100 by 10 mm.

In building up a specific gage block combination, use as few blocks as possible. You should know the sizes of the gage blocks in the set available. ***Start*** by selecting gage blocks which ***will remove the right-hand figure in the decimal size*** which you wish to build. Then select blocks which will remove the next right-hand decimal, and so on. Example will illustrate the procedure:

Build up ***48.357*** mm: 1.007+1.05+1.3+5+40=48.357 mm.

Angle gage blocks are precision tools used for accurate measurement of angles. A set of 16 may be used for measuring 356,400 angles in steps of 1 second up to 99 degrees. These angle gage blocks may be wrung together in various combinations, just as rectangular gage blocks are. Angle blocks can also be wrung together for inspection of a simple angle on a part.

Angle blocks are manufactured in two accuracy classifications: **laboratory master angle gage blocks,** which are the most expensive, have an accuracy classification of plus or minus 1/4 second; **toolroom angle gage blocks** have an accuracy of plus or minus 1 second.

Angle gage blocks are so designed that they may be combined in plus or minus positions. One end of each angle block is marked **plus,** while the opposite end is marked **minus.** Several examples will illustrate how the blocks may be combined in either position, thus forming different angles. The plus end of a 15° angle block may be wrung together with the plus end of a 5° block to form a 20° angle. Wringing the plus end of the 15° block together with the minus end of the 5° block forms an angle of 10°. The angle blocks may be wrung together to form angles in steps of degrees, minutes, seconds, or in any combination of these units.

Order of performing work

Measurement with indicating snap gage

A) Write down the metrological characteristics of the given measuring tools:
1. Division – ……. mm (It is written on the main face. For example, in fig. 11 division is 0.01 mm).
2. Range of measurements on the dial scale – ……….. mm (Number of division on the small (additional) scale (face). For example, in fig. 11 there is now a small scale, that is why the range of measurements on the dial scale is ±1 mm).
3. Range of measurements of the snap – ……………... mm (It is written on the snap. For example, in fig. 12 the range of measurements of the snap is 0 - 50 mm).
4. Measuring transition – …………….. mm. (We push the measuring rod and count transition of the short pointer).

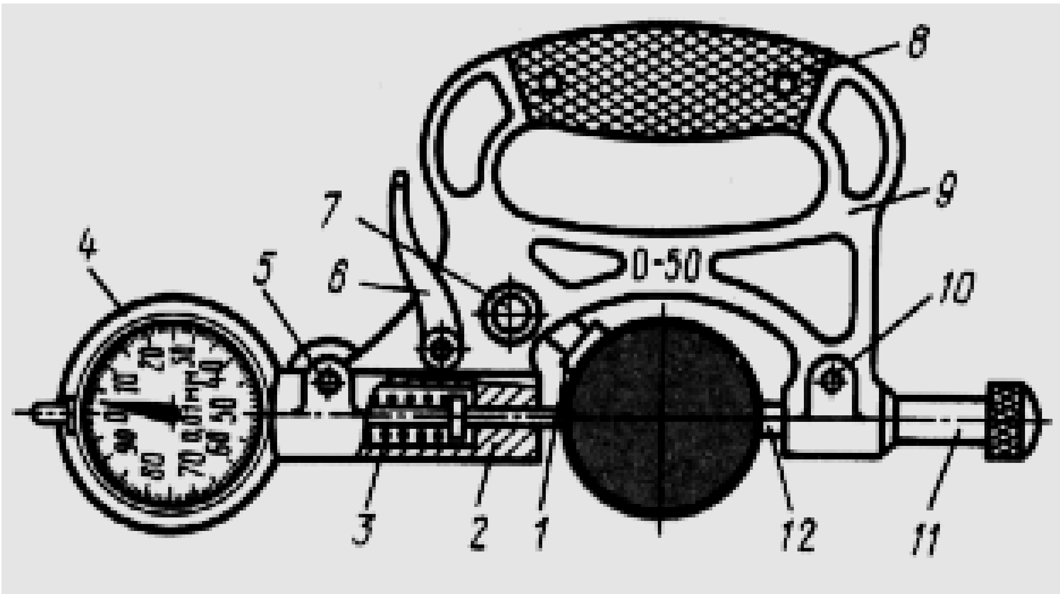


Fig. 11. Indicating snap gage

B) Measurement:
1. Measurement with a vernier caliper VC ……… (we write down the type of vernier caliper, division, range of measurements) – …………… mm.
2. Adjusted size – …………. mm.
Gage block ***GB*** =……………… (we write down the set of used gage blocks).

3. We place the composed gage block between the measuring rod and adjusted rod 12 and push the adjusted rod until the small (short) pointer is against division 2 or 3 (it is necessary to adjust the indicator short hand not against 0 in order that the reading should be possible if the dimension of a part proves to be less than we thought). After that we have to fasten clamp screw 10. In order to make reading easier, we have to turn the main face 4 of the indicator until the stroke of 0 is set against the long hand. We have adjusted the instrument, and ***after that we must not turn the face of the indicator***.

Reading of adjustment $\mathbf{S_A}$ = ……….. mm.

4. We place the part between measuring and adjusted rods pushing the lever 6, lower the lever 6, look at the face and find the largest reading carefully transiting the controlled part.

Reading of measurement $\mathbf{S_M}$ = ……….. mm.

5. We define the relative transference $\mathbf{\Delta_R} = \mathbf{S_M} - \mathbf{S_A}$ = ……….. mm.

6. We calculate the general dimension (real or actual size):

$$\mathbf{d_a} = \boldsymbol{GB} + \mathbf{\Delta_R} = \text{……….. mm.}$$

7. We compare dimensions measured with an indicating snap gage and a vernier caliper – the difference should not be more than 0.1 mm. If it more it is necessary to check or even to repeat measurements.

Measurement with dial indicating hole gage

A) ***Measuring characteristics***

1. Division – ……. mm.
2. Range of measurements on the dial scale – ……….. mm
3. Range of measurements of the indicating hole gage – ……………... mm.
4. Measuring transition – …………….. mm. (We push the measuring rod and count transition of the short pointer).

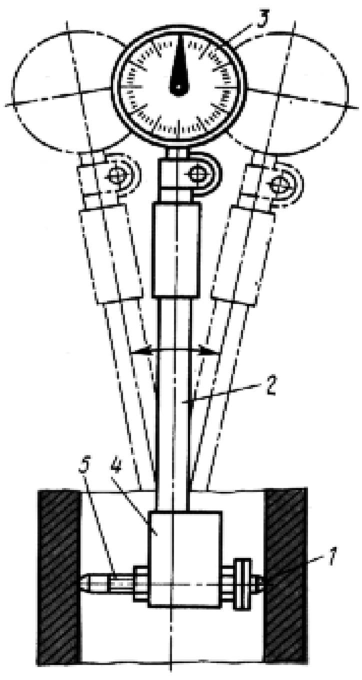


Fig. 12. Measurement with a dial indicating hole gage

B) ***Measurement***

1. Measurement with a vernier caliper VC ……… (we write down the type of vernier caliper, division, range of measurements) – …………… mm.
2. Adjusted size – …………. mm.

Gage block ***GB*** =……………………….. (we write the set of used gage blocks).

3. We place the composed gage block between the parallel plates and clamp them in the holder. Then we screw on the corresponding measuring rod 5 in the head 4 of indicating hole gage 2 (fig. 12), place our indicating hole gage between the parallel plates of the holder and roughly adjust, revolving adjusted rod 5 until the ***short pointer*** is against division 2 or 3 of a small scale (it is necessary to

adjust the indicator short hand not against 0 that the reading should be possible if the dimension of a part proves to be less than we thought). After that we have to fasten the nut of the adjusted rod. Then we turn the indicating hole gage in the axial plane and find the largest reading (as in fig. 13). In order to make reading easier, we have to turn the main face 3 of the indicator until the stroke of 0 is set against the long hand. We have adjusted the instrument, and ***after that we must not turn the face of the indicator***.

Reading of adjustment $\mathbf{S_A}$ = ……….. mm.

4. We place the indicating hole gage in the part hole, turn the indicating hole gage in the axial plane and find the largest reading (fig. 13). Note: first of all we insert the measuring rod and then – the adjusted rod 5.

Reading of measurement $\mathbf{S_M}$ = ……….. mm.

5. We define the relative transference $\mathbf{\Delta_R = S_A} - \mathbf{S_M}$ = ……….. mm.

6. We calculate the general dimension (real or actual size):

$$\mathbf{D_r} = \boldsymbol{GB} + \mathbf{\Delta_R} = \ldots\ \text{mm.}$$

7. We compare dimensions measured with an indicating snap gage and a vernier caliper – difference should not be more than 0.1 mm. If it is more, it is necessary to check or even repeat measurements.

Laboratory work №3
"Tolerances and Fits"

The purpose of work:
1. To learn to choose fits.
2. To acquire skills of defining deviations and drawing of tolerance zones.
3. To estimate the accuracy of controlled parts and write down the corresponding designations in the drawing.

1. Tolerance zones

The terms used in dimensioning limits of size are so interrelated that they should be understood clearly for correct interpretation of dimensions.

Actual size is a size measured with permissible accuracy.

To understand it better we place components (parts) so that the lower part of the surface must be set against a certain level without looking at the actual size (fig.1). The size of the **shaft** is denoted by **d**, the size of the **hole** is denoted by **D** (fig. 3). As a shaft we consider all the elements of the part which are external, and a hole is the element that is internal.

In accordance with the ISO standards the shaft size is denoted, for example, by 30g6. Figure 30 shows the basic size in millimeters. This size is calculated by engineers in accordance with the requirements of strength, rigidness, etc. That is why they account only whole millimeters of size. But the movement of the mating parts (the hole and the shaft) is obtained by the difference of the actual sizes, which makes up only hundredth fractions of a millimeter. The **basic** size is the size from which the limits of size are derived by the application of the fundamental deviation and tolerances. The basic size is denoted by a figure and in the picture we draw a line from which the limits of size are derived by the application of the fundamental deviation and tolerances too. This line is called a **zero line** (fig. 1).

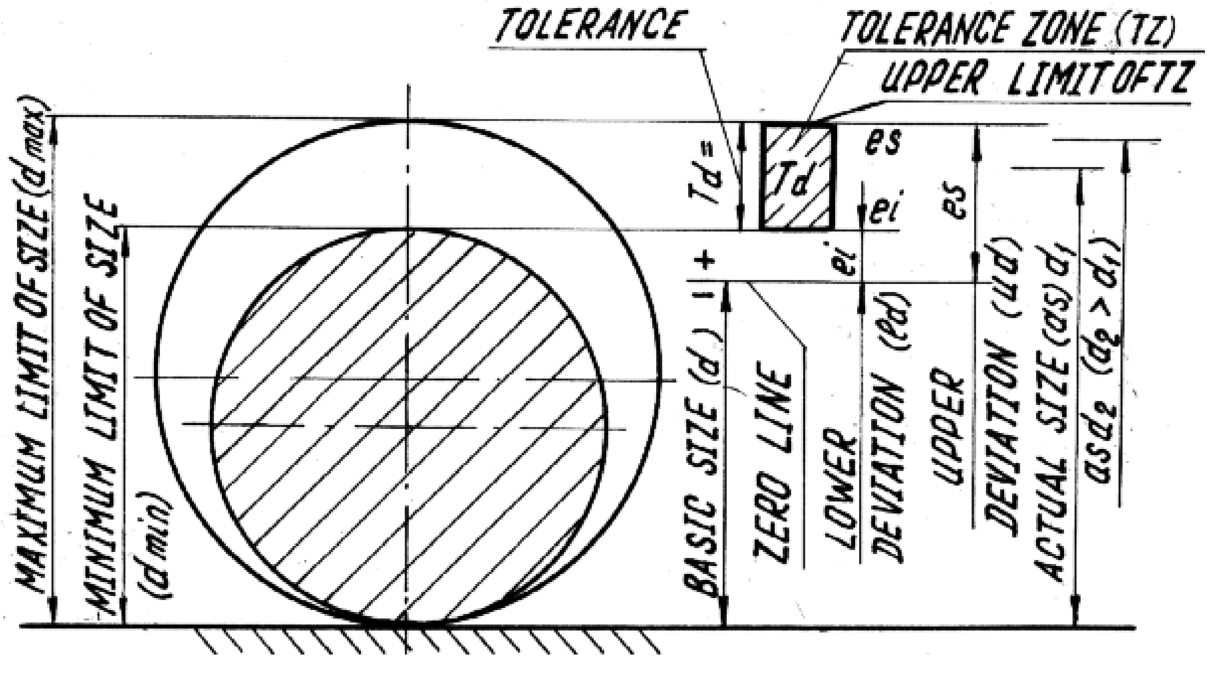


Fig. 1. A scheme of the shaft tolerance zone.

The **fundamental deviation** is denoted by a letter: it is the deviation between the basic size (zero line) and the nearest limit of a tolerance zone (fig. 1, 4). We read the fundamental deviation value in the table of fundamental deviations (table 1). The **positive sign** shows that the fundamental deviation is laid up from the zero line. The **negative sign** shows that the fundamental deviation is laid low from the zero line.

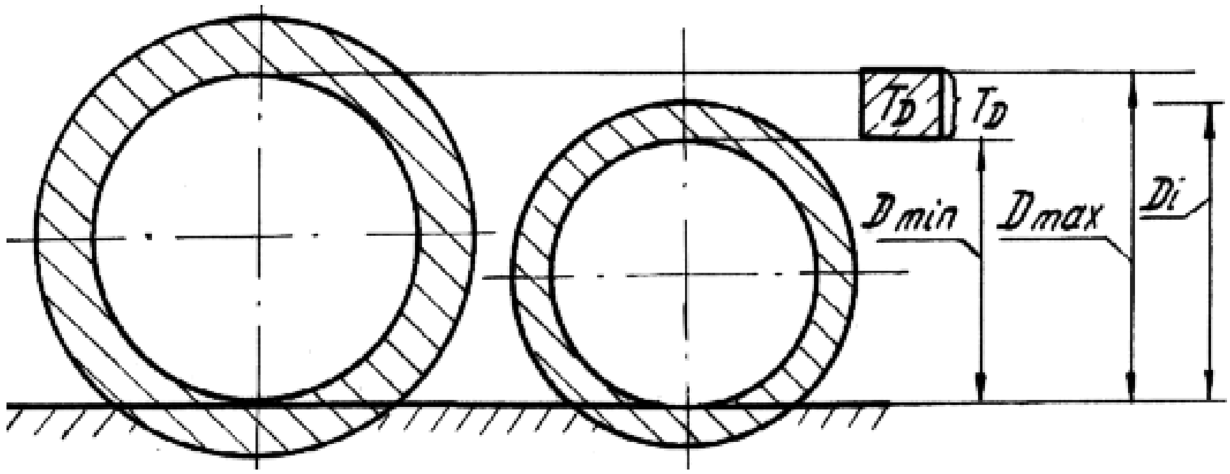


Fig. 2. A scheme of the hole tolerance zone.

The figure after the letter shows a **grade of tolerance** that determines the value of tolerance (table 2). **Tolerance** is the total permissible variation of size. It is the difference between the maximum and minimum limits of size. Numbers 6 and 7 grades of tolerance are accuracy and are obtained by grinding, accurate turning processing, etc. Numbers 8, 9, 10 are medium accuracy; 11, 12 are rough enough; 14, 15 ,16 are very rough.

The values of tolerance and fundamental deviation depend on the size of a part. The whole range of sizes is divided into intervals of sizes within which the values of tolerance and fundamental deviation are equal. In tables the values of tolerance and fundamental deviation are written in micrometers.

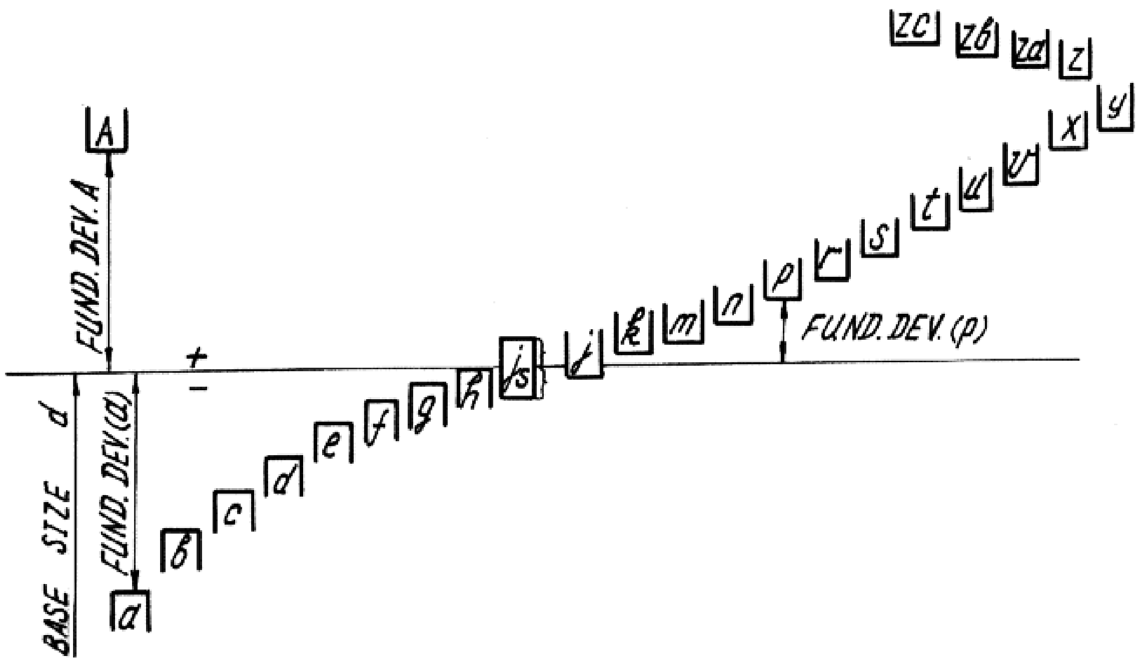


Fig. 3. A scheme of fundamental deviations of shafts.

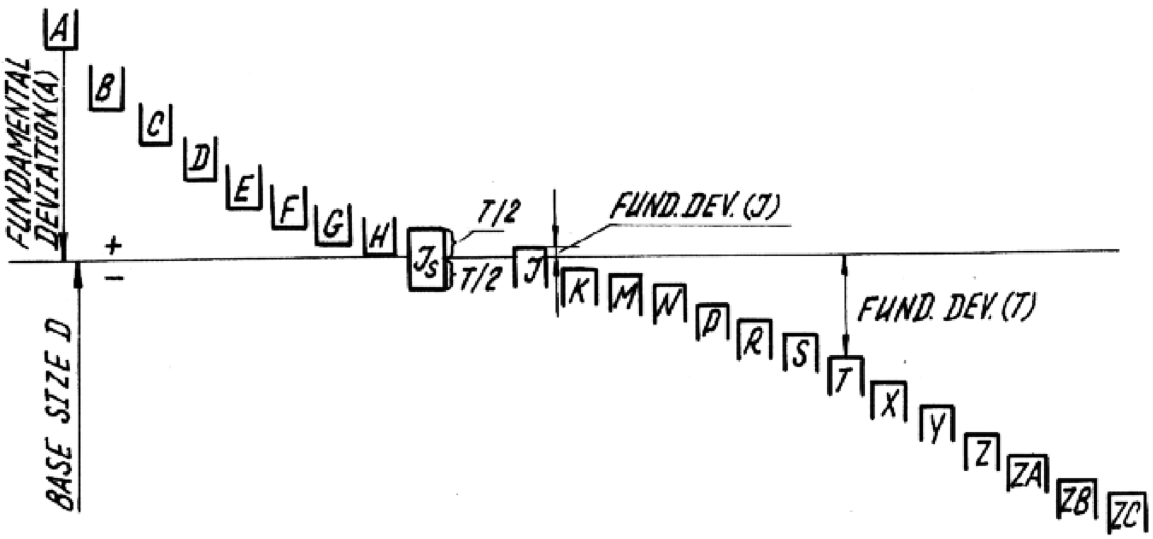


Fig. 4. A scheme of fundamental deviations of holes.

Table 1. Fundamental deviations, μm (1μm = 0.001 mm).

Size, mm	a	b	c	d	e	f	g	j		k		m	n	p	r	s	t	u	v	x	y	z
	For all numbers of grades of tolerance							5,6	7	4 -7	<3,>7	For all numbers of grades of tolerance										
from 1- befor 3	-270	-140	-60	-20	-14	-6	-2	-2	-4	0	0	+2	+4	+6	+10	+14	---	+18	---	+20	---	+26
3 - 6	-270	-140	-70	-30	-20	-10	-4	-2	-4	+1	0	+4	+8	+12	+15	+19	---	+23	---	+28	---	+35
6 - 10	-280	-150	-80	-40	-25	-13	-5	-2	-5	+1	0	+6	+10	+15	+19	+23	---	+28	---	+34	---	+42
10 - 18	-290	-150	-95	-50	-32	-16	-6	-3	-6	+1	0	+7	+12	+18	+23	+28	---	+33	---	+40	---	+50
18 - 30	-300	-160	-110	-65	-40	-20	-7	-4	-8	+2	0	8	+15	+22	+28	+35	+41	+48	+55	+64	+75	+88
30 - 40	-310	-170	-120	-80	-50	-25	-9	-5	-10	+2	0	9	+17	+26	+34	+43	+48	+60	+68	+80	+94	+112
40 - 50	-320	-180	-130	-80	-50	-25	-9	-5	-10	+2	0	9	+17	+26	+34	+43	+54	+70	+81	+97	+114	+136
50 - 65	-340	-190	-140	-100	-60	-30	-10	-7	-12	+2	0	11	+20	+32	+41	+53	+66	+87	+102	+122	+144	+172
65 - 80	-360	-200	-150	-100	-60	-30	-10	-7	-12	+2	0	11	+20	+32	+43	+59	+75	+102	+120	+146	+174	+210
80 100	-380	-220	-170	-120	-72	-36	-12	-9	-15	+3	0	13	+23	+37	+51	+71	+91	+124	+146	+178	+214	+258
100 - 120	-410	-240	-180	-120	-72	-36	-12	-9	-15	+3	0	13	+23	+37	+54	+79	+104	+144	+172	+210	+254	+310

Table 2. Tolerances, μm.

Size, mm	A number of grades of tolerance																			
	01	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1 - 3	0.3	0.5	0.8	1.2	2	3	4	6	10	14	25	40	60	100	140	250	400	600	1000	1400
3 - 6	0.4	0.6	1	1.5	2.5	4	5	8	12	18	30	48	75	120	180	300	480	750	1200	1800
6 - 10	0.4	0.6	1	1.5	2.5	4	6	9	15	22	36	58	90	150	220	360	580	900	1500	2200
10 - 18	0.5	0.8	1.2	2	3	5	8	11	18	27	43	70	110	180	270	430	700	1100	1800	2700
18 - 30	0.6	1	1.5	2.5	4	6	9	13	21	33	52	84	130	210	330	520	840	1300	2100	3300
30 - 50	0.6	1	1.5	2.5	4	7	11	16	25	39	62	100	160	250	390	620	1000	1600	2500	3900
50 - 80	0.8	1.2	2	3	5	8	13	19	30	46	74	120	190	300	460	740	1200	1900	3000	4600
80 - 120	1	1.5	2.5	4	6	10	15	22	35	54	87	140	220	350	540	870	1400	2200	3500	5400
units of tolerance (a)	---	---	---	----	---	---	7	10	16	25	40	64	100	160	250	400	640	1000	1600	2500

In our example 30g6 the fundamental deviation **fd** in accordance with the letter **g** is -7μm = -0.007mm (table 1). The size tolerance is T_d=13μm in accordance with the number **6** of the grade of tolerance (table 2). The upper deviation **es** is equal to the fundamental deviation **fd** in this example: es=-7μm, fig. 5. We define the lower deviation **ei**: ei=-7-13=-20μm. A lower limit of the tolerance zone corresponds to the lower deviation. An upper limit of the tolerance zone corresponds to the upper deviation. We can write: $30g6\left(^{-0.007}_{-0.020}\right)$ or $30^{-0.007}_{-0.02}$ mm. The maximum limit of the size: $d_{max}=d_{basic}+es$=30+(-0.007)=29.993mm.

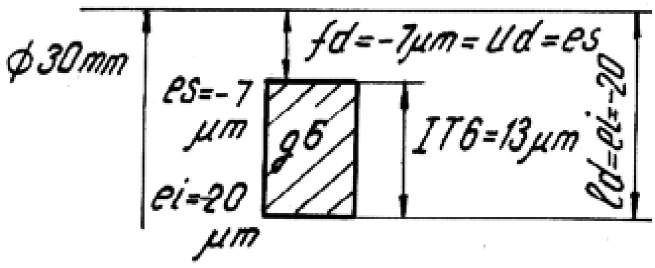


Fig. 5. A scheme of the tolerance zone 30g6.

The minimum limit of the size: $d_{min}=d_{basic}+ei$=30+(-0.02)=29.98 mm. The right size is settled between 29.98 and 29.993 mm, including the size limits.

If the fundamental deviation proves positive we will draw analogy between what we have written before.

For example 30s7: the fundamental deviation **fd** in accordance with the letter **s** is +35μm = +0.035mm (table 1). The size tolerance is T_d=21μm in accordance with number **7** of the grade of tolerance (table 2).The lower deviation **ei** is equal to the fundamental deviation **fd** in this example ei=+35μm. We define the upper deviation **es**: es=+35+21=+56μm. We can write: $30s7\left(^{+0.056}_{+0.035}\right)$ or $30^{+0.056}_{+0.035}$ mm (fig. 6). The maximum limit of size, mm: $d_{max}=d_{basic}+es$= 30+ (+0.056) = 30.056. The minimum limit of size: $d_{min}=d_{basic}+ei$ = 30+ (+0.035) = 30.035 mm. The right size is settled between 30.035 and 30.056 mm including the size limits.

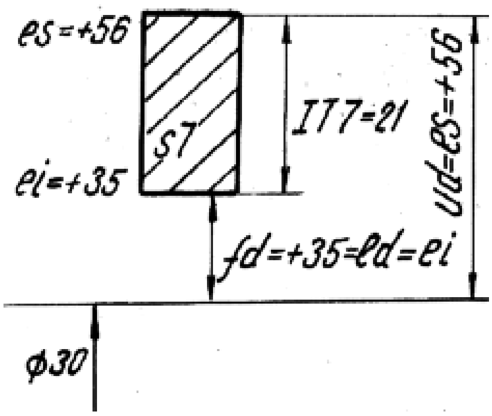


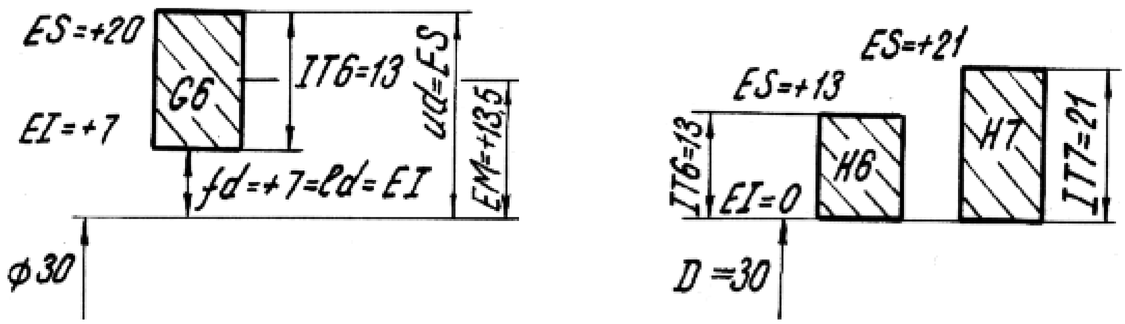
Fig. 6. A scheme of the tolerance zone 30s7.

The hole standard is analogous to the shaft standard but the arrangement of the fundamental deviations is like a mirror, and the fundamental deviations are denoted by a capital letter (fig.4).

For example, for 30G6 the fundamental deviation is +7μm likely -7μm for the shaft 30g6. A lower deviation coincides with the fundamental deviation: EI=+7μm. The size tolerance is T_D=13μm. The upper deviation is ES=+7+13=+20μm. We can write: $30G6(^{+0.020}_{+0.007})$ or $30^{+0.020}_{+0.007}$ mm.

There are standards where deviations are already defined. First of all, we find the standard for a hole or a shaft, then we find the necessary grade of a tolerance number. After that we find the necessary letter of the fundamental deviation (for example, g6). At the intersection of the letter column with a size line we obtain both deviations (for example, 30g6: $^{-7}_{-20}$ μm).

Sometimes we can use the ***mean deviation***: em=(es+ei)/2 or EM=(ES+EI)/2. For example, for $30G6(^{+0.020}_{+0.007})$ EM=(+0.02+0.007)/2=+0.0135 mm.



a b

Fig. 7. A scheme of the tolerance zones 30G6 (a) and basic holes H6 and H7 (b).

In order to reduce the quantity of tolerance zones we have to use a tolerance zone for a preferable application. These zones are marked in standards.

It is better if the lower deviation of a hole will be equal to 0 to reduce the number of cutting tools such as drills, reamers and others. If the lower deviation is not equal to 0 we must have cutting tools of several sizes, for example, 10.1mm, 10.2mm, 10.3mm, etc. When we use the hole tolerance zone with a zero lower deviation we can use only tools with whole millimeters, for example, 10mm, 11mm, 12mm, etc. These tolerance zones are H6, H7, H8, etc. This hole is called a **basic hole**.

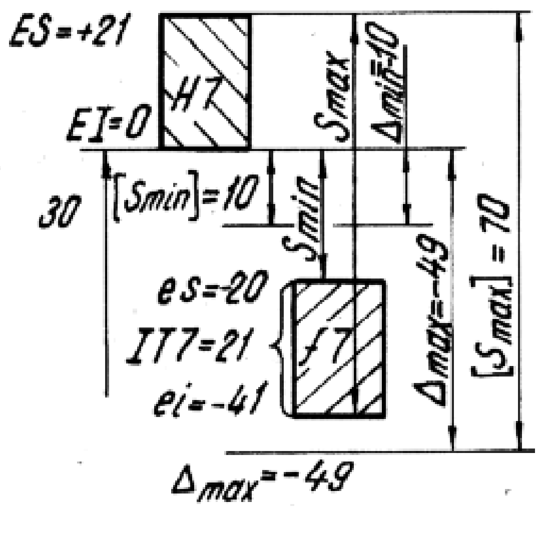


Fig. 8. A scheme of the clearance fit.

2. Fits

A hole together with a shaft makes a fit. Fits are divided into: ***1) clearance fits; 2) interference fits; 3) transition fits***.

When we deal with ***clearance fits*** a shaft is always smaller than a hole and we obtain only clearances between the minimum clearance and maximum clearance (fig. 8). We can define the tolerance of a fit:

$$T_F=T_S= S_{max}-S_{min}= T_D+T_d.$$

Clearance fits are used for moveable

mating parts:

1. Rough clearance fits which are widely used – **H14/h14**, H11/h11, **H11/d11** (the last with a large guaranteed clearance).
2. Clearance fits with medium accuracy (which are widely used) – H9/h9, **H9/f8**.
3. Clearance fits with a high accuracy (which are widely used) – H7/h6, **H7/g6**, H7/f7. The second fit has the least guaranteed clearance and is used for fits of gears with shafts when the moveable is obligatory.

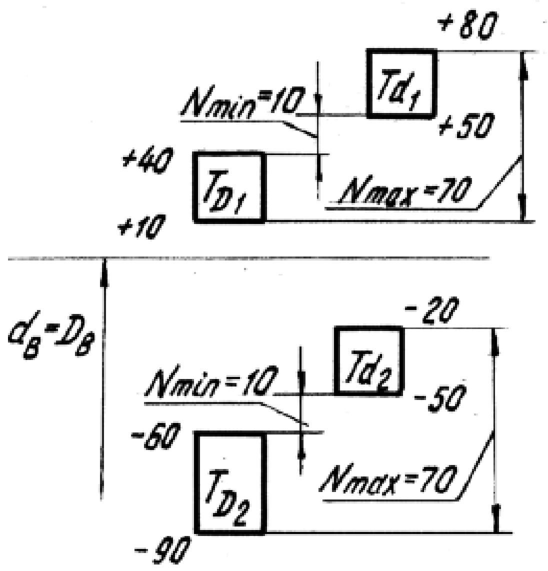


Fig. 9. A scheme of the interference fit.

When we deal with ***interference fits*** a shaft is always larger than a hole and we obtain only interferences between the minimum interference and maximum interferences (fig. 9). We can define the tolerance of a fit: T_F=T_N= =N_{max}-N_{min}= T_D+T_d.

Interference fits are used to transmit the rotation loading without a key or slit. Interference fits are used only with a high accuracy: H7/p6 (with a very small interference and can not transmit the rotation loading and is used only for good coaxiality of mating parts), H7/r6, H7/s6 or **H7/s7** (the last is more preferable for a medium rotation loading), H7/t7, H8/u8 (the last is used to transmit a large rotation loading but it is necessary to calculate the strength of mating parts).

When we deal with ***transition fits*** we can obtain clearances or interferences dependent on the actual size of a hole and a shaft (fig. 10). These fits have S_{max} and N_{max}. We can define the tolerance of a fit: T_F = N_{max}+S_{max} = T_D+T_d.

Transition fits are used for good coaxiality rather than for a large loading of the assembly: H7/j_s6, H7/j6, H7/k6, H7/m6, **H7/n6** (the last is widely used).

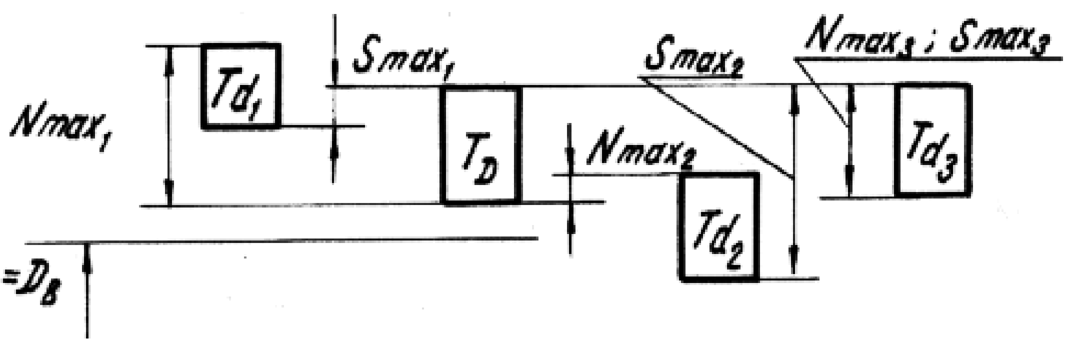


Fig. 10. A scheme of transitions fits: 1) T_D/T_{d1}; 2) T_D/T_{d2}; 3) T_D/T_{d3}.

We can nominate a fit using the hole-basis system of fits or the shaft-basis system of fits. When we nominate a fit using the hole-basis system of fits, a hole is made as the basic hole (H) and we select (pick out) a shaft tolerance zone to this basic hole in order to obtain the necessary fit.

When we nominate a fit using the shaft-basis system of fits, the shaft is made as the basic shaft (h) and we select a hole tolerance zone to this basic shaft in order to obtain the necessary fit.

The hole-basis system of fits is more preferable than the shaft-basis system of fits.

For example, it is necessary to pick out a fit if the basic size of the fit is 30 mm, the maximum clearance must be less than 70 μm (S_{max}<70 μm), the minimum clearance must be more than 10 μm (S_{min}>10 μm).

d_b=30 mm, [S_{max}]=70 μm , [S_{min}]=10 μm.

1. We define the approximate tolerance of the fit:

$$T_F = T_S = [S_{max}] - [S_{min}] = 70 – 10 = 60\ \mu m.$$

2. We define the approximate tolerance of the hole and shaft, considering $T_D = T_d$. If $T_D + T_d = T_F$, that is $T_D = T_F/2 = 60/2 = 30$ μm. [T_D]=30 μm.
3. We define the grade of tolerance: the tolerance must be less than 30 μm. For d=30 mm that is number 7 (IT7 = 21 μm). For number 8 it is not permissible (IT8 = 33 μm > [T_D]=30 μm).
4. We draw a tolerance zone for the hole 30H7 (fig. 11). We have nominated the letter H as we use the basic hole (a hole-basis system). The lower deviation is 0, the upper deviation is +21 μm.

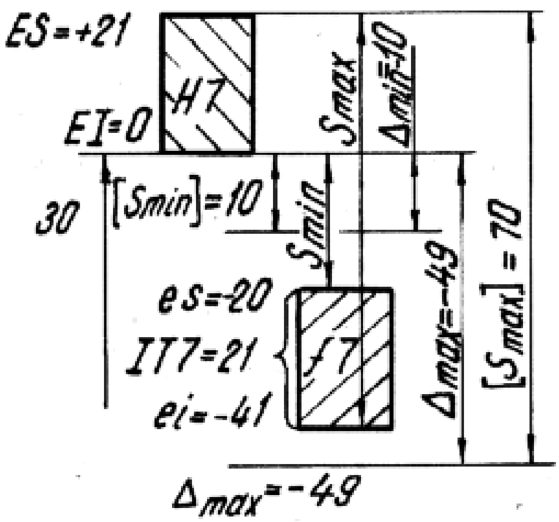


Fig. 11. A scheme of the fit 30H7/f7.

5. We lay [S_{max}]=70 μm and [S_{min}]=10 μm as it is shown in fig.11.
6. The fundamental deviation must be less than -10 μm and the lower deviation must be larger than -49 μm. A shaft tolerance zone must settled between -10 μm and -49 μm, fig.11.
7. Looking at the fundamental deviation table we define the letter of the shaft tolerance zone. This is the letter f (the fundamental deviation fd=-20 μm).
8. We define the shaft tolerance: IT7=21 μm.
9. We define the lower deviation: ei=-20-21=-41 μm.
10. We define clearances: S_{min} = 20 μm > [S_{min}] = 10 μm;

S_{max} = ES – ei = =+21 - (-41) = 62 μm < [S_{max}] = 70 μm.

All conditions are fulfilled.

11. We have defined the fit: H7/f7 or 30H7/f7.

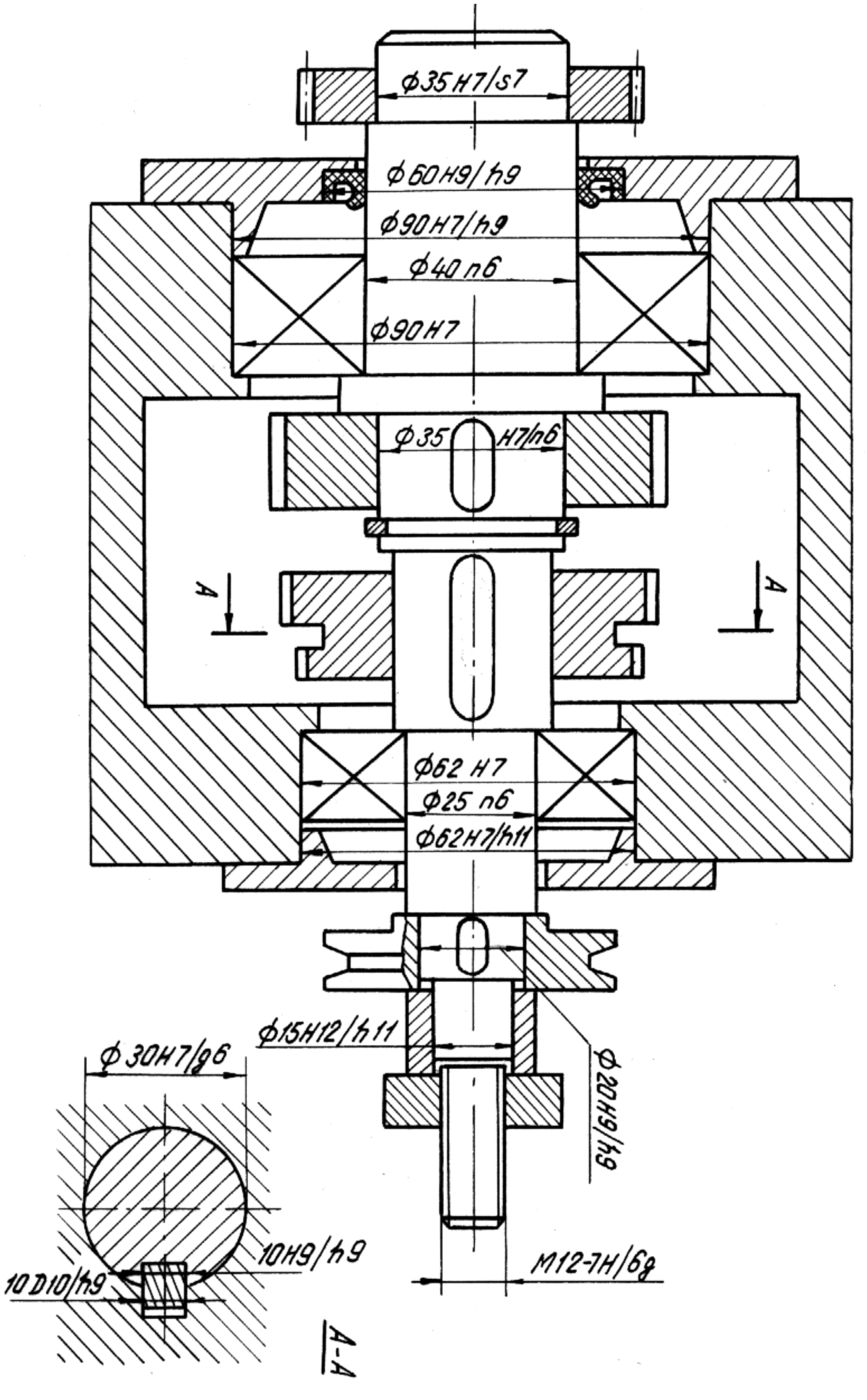


Fig. 12. An assembly drawing.

A division of a measuring tool (responsibility) has to be from 5 to 10 times less than the size tolerance of the measured part. For example, for $50_{-0.3}$ mm a division has to be 0.05…0.03. That is why we can use a veirnier caliper (with a division of 0.05 mm) or micrometer (with a division of 0.01 mm, range of 25 – 50 mm).

Order of performing work

1. It is necessary to transmit loading 10 N·m by a gear wheel. Write down the designations of the fit for the diameter of 60 mm. Draw tolerance zones for the fit. Determine the limit clearances or interferences.
2. It is necessary to transmit loading 300 N·m by a gear wheel. Write down the designations of the fit for the diameter of 60 mm. Draw tolerance zones for the fit. Determine the limit clearances or interferences.
3. It is necessary to mount an indicator pointer on the smooth axle. Write down the designations of the fit for the diameter of 2 mm. Draw tolerance zones for the fit. Determine the limit clearances or interferences. Draw tolerance zones for the same fit with the basic diameter of 60 mm. Determine the limit clearances or interferences.
4. Write down the designations of the fit for the gear wheel which is moved along the key shaft with diameter of 60 mm. Draw tolerance zones for the fit. Determine the limit clearances or interferences.
5. Write down the designations of the fit for the pulley which is mounted on the key shaft with the diameter of 60 mm. Reassembling is frequent, the frequency of shaft revolving is 200 rpm. Draw tolerance zones for the fit. Determine the limit clearances or interferences.
6. Write down the designations of the fit for the pulley which is mounted on the key shaft with the diameter of 60 mm. Reassembling is frequent, the frequency of shaft revolving is 3000 rpm. Draw tolerance zones for the fit. Determine the limit clearances or interferences.
7. Write down the designations of the fit for the pulley which is mounted on the key shaft with the diameter of 60 mm. Reassembling is seldom, the frequency of shaft revolving is 3000 rpm. Draw tolerance zones for the fit. Determine the limit clearances or interferences.
8. It is necessary to pick out a fit if the basic size of the fit is 60 mm, the maximum clearance must be less than 62 μm (S_{max} < 62 μm), the minimum clearance must be more than 9 μm (S_{min} > 9 μm). Draw tolerance zones for the fit. Determine the limit clearances.
9. It is necessary to pick out a fit if the basic size of the fit is 60 mm, the maximum interference must be less than 85 μm (N_{max} < 85 μm), the minimum interference must be more than 20 μm (N_{min} > 20 μm). Draw tolerance zones for the fit. Determine the limit interferences.
10. Write the names of all measuring tools required for inspection of sizes.

Laboratory work №4
"Special Forms of Fits"

The purpose of work:
1. To learn to choose fits.
2. To acquire skills of defining deviations and drawing of tolerance zones.
3. To estimate the accuracy of controlled parts and write down the corresponding designations in the drawing.

1. Fits for Rolling Contact Bearing

Bearings differ according to the class of accuracy: 0; 6; 5; 4; 2. The less the number of the class the higher is the accuracy. Although the size of inner race is a «hole», the tolerance zone is nominated inside of the basic size. This permits us to use tolerance zones of shaft such as k6, m6, n6 to make interference fits.

When a load is directed to the unchangeable place of the inner surface of race we have a local loading of race and this race is mounted on the shaft or into the hole with clearance. This is done in order that the loading place may change and the wear of the race inner surface is more uniform, so its work life increases. Very often the outside race is loaded this way and a fit is used which is usually H7/b0, where **b0** is the tolerance zone of the outside race (**b** means «bearing », **0** is the class of accuracy of the bearing). In accordance with the class of accuracy of the bearing we define the value of deviations in the standard of bearings (see table 1).

The other race has no local loading and the fit with interference is used. Usually the B0/n6 fit is used where B0 is the tolerance zone of the inner race (***B*** means «bearing », 0 is the class of accuracy of the bearing). In accordance with the class of accuracy of the bearing we define the value of deviations in the standard of bearings (see table 1).

Table 1. Deviations of bearing races.

A basic diameter d (D), mm	Deviations of **inner** race, μm				Deviations of **outside** race, μm			
	The class of accuracy is **0**		The class of accuracy is **6**		The class of accuracy is **0**		The class of accuracy is **6**	
	es	ei	es	ei	ES	EI	ES	EI
0.6 - 2.5	+1	-9	+1	-8	---	----	---	---
2.5 - 10	+2	-10	+1	-8	+1	-9	+1	-8
10 - 18	+3	-11	+1	-8	+2	-10	+1	-8
18 - 30	+3	-13	+1	-9	+2	-11	+1	-9
30 - 50	+3	-15	+1	-11	+3	-14	+2	-11
50 - 80	+4	-19	+2	-14	+4	-17	+2	-13
80 - 120	+5	-25	+3	-18	+5	-20	+2	-15
120 - 180	+6	-31	+3	-21	+6	-24	+3	-18

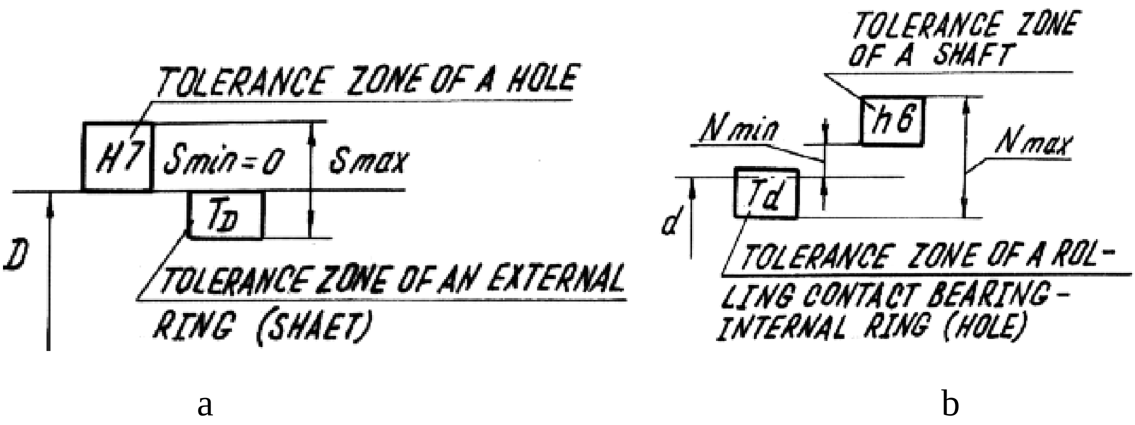


Fig. 1. A scheme of the bearing fit.

Bearings are industrial goods which are produced at specialized plants and never remade. That is why in these bearing fits we may show only the tolerance zone of a shaft or a hole with which the bearing contact: ***30n6*** (we show only the tolerance zone of the shaft on which the bearing is mounted); ***60H7*** (we show only the tolerance zone of the hole into which the bearing is mounted).

2. Selective Assembly

Sometimes the requirement of the accuracy of a fit is so high that it cannot be achieved using the ordinary methods. In this case, one can use the method of selective assembly. The tolerance zones of a hole and shaft are divided into groups as shown in fig. 2. After that we assemble the hole and the shaft using only the equal numbers of groups.

The tolerance of the group fit is:

$T_{F.g}=T_{S.g}=S_{max.g}-S_{min.g}=T_{D.g}+T_{d.g}$ (1)

$T_{S.g}<T_S=S_{max}-S_{min}$ (2)

Usually $T_D=T_d$ and $T_{D.g}=T_{d.g}$. Then $T_{S.g}=2T_{D.g}$.

$S_{min.g}> S_{min}$

$S_{min.g}=S_{min}+T_D-T_D/n$, (3)

where **n** is the quantity of groups.

For interference fits:

$N_{max.g}=N_{max}-T_D+T_D/n$. (4)

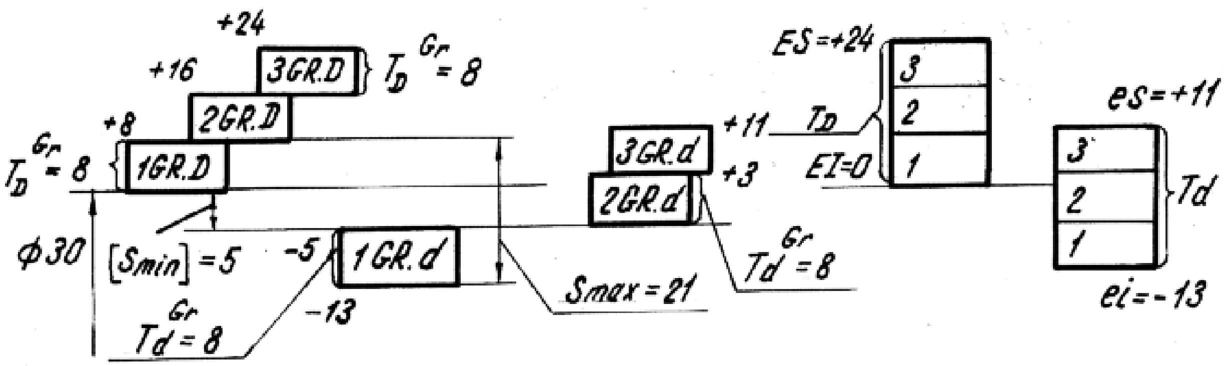
Usually n=2...3, but sometimes n=10 (in the bearing industry).

For example, it is necessary to make a fit with $S_{max}<[S_{max}]=21$ μm and $S_{min}>[S_{min}]=5$ μm for the basic size of 50 mm. But we can produce parts with a tolerance of T=25 μm.

If we used the ordinary method we could not meet the requirements, $S_{max}>[S_{max}]$.

We can use the method of selective assembly.

1. We draw the tolerance zone of a hole with the tolerance T=25 μm. It is preferable to use fits of hole-basis system of fits that is why we choose the tolerance zone of the hole as H (fig.2, a).
2. We lay $[S_{min}]$=5 μm. This is the upper limit of the group tolerance zone of a shaft (es_g=5μm).
3. We define the tolerance of the group fit: $T_{S.g}=[S_{max}] - [S_{min}]=21 - 5 = 16$ μm.
4. We define the tolerance of the group: $T_{D.g} = T_{d.g} = = T_{S.g}/2 = 16/2 = 8$ μm.
5. We lay ES_g=+8 μm into the tolerance zone of the hole.
6. We lay $[S_{max}]$=21 μm and draw the lower limit of the group tolerance zone of the shaft (ei_g=13μm).
7. We define the number of the groups: n= $T_D/T_{D.g}$ = 25/8 = 3.1. We nominate n=3.



a b

Fig. 2. A scheme of defining tolerance zones for the selective assembly.

8. We draw other group tolerance zones of the hole.
9. We draw other group tolerance zones of the shaft.

The task has been done.

3. Key Fits

Key junctions are used for transmission of a rotary load. For these purposes we can use: 1) straight (feather) key; 2) Woodruff key; 3) taper key. Let us look at the standard of a straight key (fig. 3).

The key junction has 3 fits: on a width, on a length, on a height. The most important fit is the fit on the width. Fits are different: the fit on the width between the slot of a shaft and the key and between the slot of a sleeve and the key.

The key is always made with the tolerance zone h9. But the tolerance zones of the slot are different. Key fits are divided into:

1. **Free junction**. The fit between the **shaft slot** and the **key** (**SS/k**) is H9/h9. The fit between the **hole slot** and the **key** (**HS/k**) is D10/h9.
2. **Normal junction**: **SS/k** is N9/h9, **HS/k** is J_s9/h9.
3. **Strong junction**: **SS/k** is P9/h9, **HS/k** is also P9/h9.

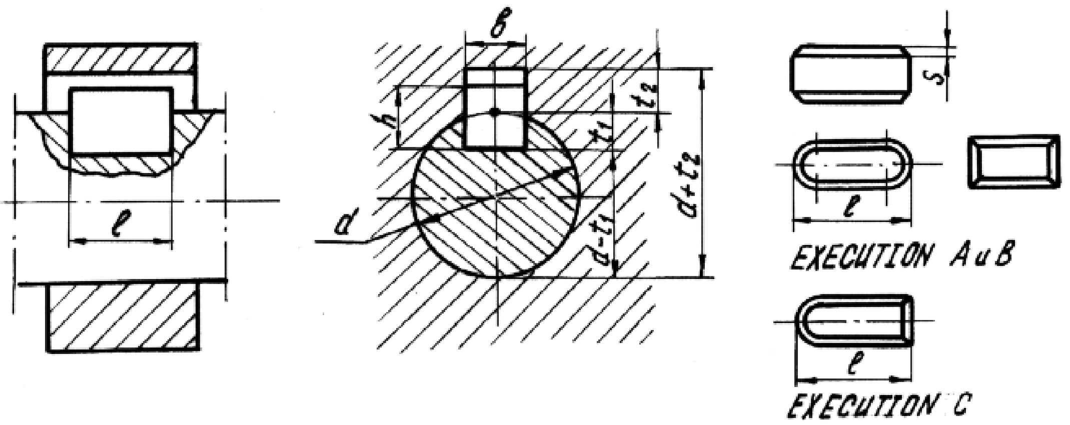


Fig. 3. A scheme of tolerance zones for the key junction.

The free junction is usually used. This type is always used for the move junction.

Strong junction is used for exchangeable loads.

The fit **H15/h14** is always used on the **length fit**.

The height of the key is produced with the tolerance zone h9. The depth of slots is produced in accordance with a special standard for the key. There is always a clearance between the key and slots on the height.

4. Slit Fits

Slit junctions are used for the transmission of a large rotary load and for the transmission of a rotary load when there is an axle (shift) transference (fig. 4).

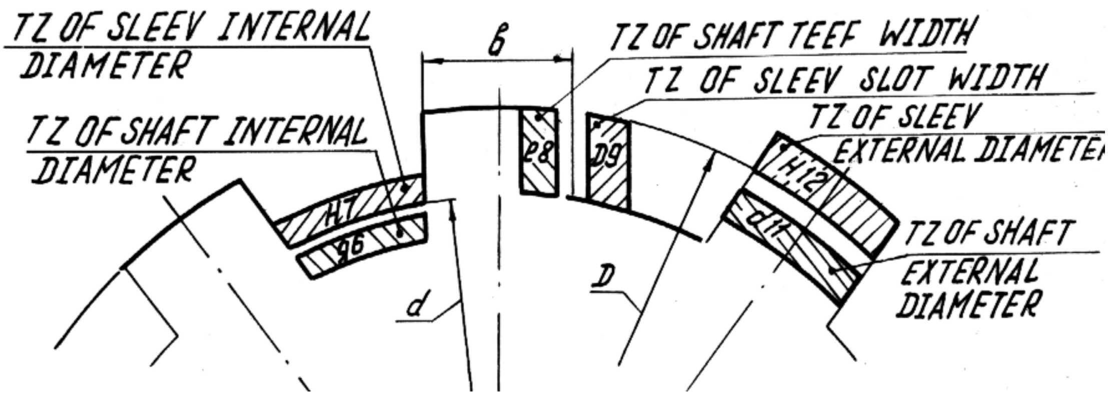


Fig. 4. A scheme of tolerance zones for the slit junction.

There are several types of slit junctions but usually the straight side slits are used. There are **2 types of centring**: on the external diameter and on the internal diameter.

Internal diameter centring is usually used because of easier production: grinding of the internal diameter of the slit hole is more technological in comparison with that of the external diameter of the slit hole.

A designation of the slit junction is, for example: d-8 x 36H7/e8 x 40H12/a11 x 7D9/f8 (fig. 4). For the sleev: d-8 x 36H7 x 40H12 x 7D9. For the shaft: d-8 x 36e8 x 40a11 x 7f8.

5. Tolerances of Angles and Cones

There are 17 grades of tolerance for angles: from 1 to 17. Designation is AT1, AT2, ..., AT17, where: AT - Angle Tolerance; 1 - grade of tolerance. The numerical values of angle tolerances (the difference between the maximum limit α_{max} and the minimum limit α_{min} of angles) one degree to another changes with the factor of increase 1.6. The degrees of accuracy 12 - 14 are coarse accuracy, the degrees of accuracy 8 - 10 are medium accuracy, the degrees of accuracy 6 - 7 are accurate. The tolerance is smaller for a greater size because for easer to measure an angle for greater length of angle. Tolerances are nominated depending on the smaller part of an angle.

The **conecity** is $C = (D - d)/L = 2tg\alpha/2$, where: D – the diameter of the large base of a cone (of a tapered shaft); d – the diameter of the small base of a cone; α - the angle of a cone; $\alpha/2$ – the angle of a slope.

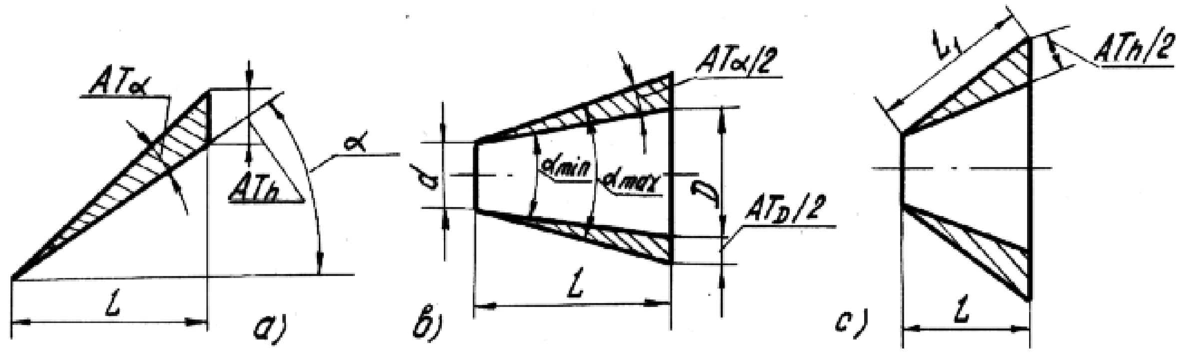


Fig.5. Disposition of tolerance zones of cones.

For each degree tolerances are established:

1. Angle tolerance AT_α, which is expressed in angle units as microradian (μrad) as an angle degree and angle minute (^{o} , $'$). Angle degrees are widely used. Round of values AT_α' are recommended to use on drawings.

2. Angle tolerance AT_h, which is expressed in millimeters (mm). This tolerance is expressed by a piece on a perpendicular to the part of an angle on the distance L_1 from the top of this angle.

3. Angle tolerance AT_D, which is expressed in millimeters by the tolerance on the difference of diameters in two perpendicular to the axis of cone sections on a specified distance between them (it is determined on a perpendicular to the axis of a cone) is used for conecity less than 1:3. Tolerances are nominated depending on

the base length L of the cone. When conecity greater tolerances are nominated depending on the forming length L_1 of the cone.

There are two ways to nominate the tolerance of a cone diameter:

1. The tolerance is nominated for a diameter. This tolerance is identical in any cross section of a cone and is limiting two cone limits, between which all points of the surface of the actual cone should settle down. The tolerance also limits the deviation of an angle of a cone, if these deviations are not limited by smaller tolerance.
2. The tolerance is specified only for a specified section of a cone. The tolerance of the form is determined by the sum of tolerances of the roundness and straightness its forming. These tolerances are nominated on the diameter of the greater basis of a cone or the diameter of a specified section of a cone.

Table 2. Tolerance of corners.

Size mm	Symbol	Unit of measurement	Grade of tolerance							
			6	7	8	9	10	11	12	17
10 - 16	AT_α	µrad	500	800	1250	1600	2500	4000	6300	63000
	AT_α	...°	1′ 43″	2′ 45″	4′ 18″	5′ 30″	8′ 35″	13′ 44″	21′ 38″	3° 36′34″
	AT_h, AT_D	µm	5	8	12.5	16 - 25	25 - 40	40 - 63	63 - 100	630 - 1000
16 - 25	AT_α	µrad	315	500	800	1250	2000	3150	5000	50000
	AT_α	...°	1′ 5″	1′ 43″	2′ 45″	4′ 18″	6′ 52″	10′ 49″	17′ 10′	2° 51′ 53″
	AT_α'	...°	1′	1′ 40″	2′ 30″	4′	6′	10′	16′	2°
	AT_h, AT_D	µm	5 - 8	8 - 12.5	12.5 - 20	20 - 32	32 - 50	50 - 80	80 - 125	800 - 1250
25 - 40	AT_α	µrad	250	400	630	1000	1600	2500	4000	40000
	AT_α	...°	52″	1′ 22″	2′ 10″	3′ 26″	5′ 30″	8′ 35″	13′ 44″	2° 17′ 30″
	AT_α'	...°	50″	1′ 20″	2′	3′	5′	8′	12′	---
	AT_h, AT_D	µm	6.3 - 10	10 - 16	16 - 25	25 - 40	40 - 63	63 - 100	100-160	1000 - 1600

The deviations for an angle are nominated chiefly symmetric, ally and can be both in plus or minus. The conic fits can be with a clearance, interference and transition fits, depending on the axial arrangement. The fits are divided by the way of fixing of axial arrangement: 1) fits with fixing by combining the constructive elements of cones (base planes); 2) fits with fixing of a specified axial displacement of cones; 3) fits with fixing of a specified axial distance between the base planes of the mating cones; 4) fits with fixing of the specified force of pressing.

The clearance fits are applied in junctions, in which it is necessary to adjust a clearance between mating parts (for example, for the bearings of a spindle). The interference fits are applied to maintain tightness and self-centering and transfer of the twisting moment. Conic fits provide easier disassembly in comparison with cylindrical junctions, and allow adjusting interference during work.

Methods and Tools for Control of Corners and Cones. There are comparative and trigonometric methods of control. The comparison of a checked corner with angle gage blocks, set squares and angle patterns are used in the first method. Conic gages are applied to the control of cones when conecity is used from 1:3 to 1:50 and the tolerance degrees of corners and cones are used from 4 to 9. The control of a stain of contact is used for estimation of the degree of cone adjoining. The application of a sine bar, gage blocks and indicator allows one to measure and check angles and cones with a high accuracy. A universal bevel protractor is applied for measurements with an accuracy of 5′ (fig. 8).

A **combination set** consists of a steel rule or blade, a square head, a center head, and a protractor head, fig. 6. The square head and the protractor head are furnished with a spirit level. Although the level is not a precision level, it is an aid in measuring angles in relation to the vertical or horizontal plane. The blade and the square head together make up a **combination square.** It may be used to lay out or test 90° or 45° angles and lay out lines parallel to an edge. It may also be used to measure the height of parts or the depth of slots or grooves.

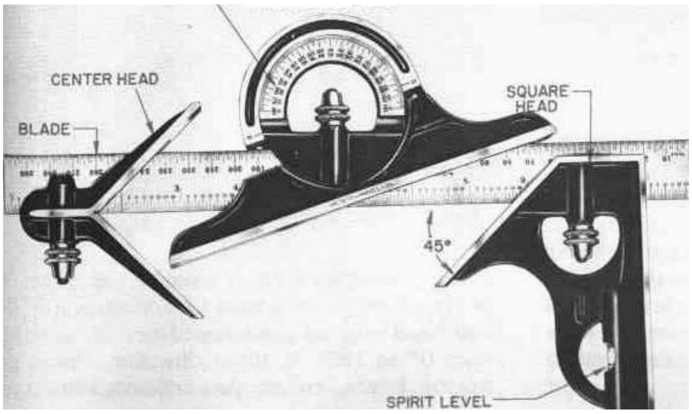


Fig. 6. Combination set.

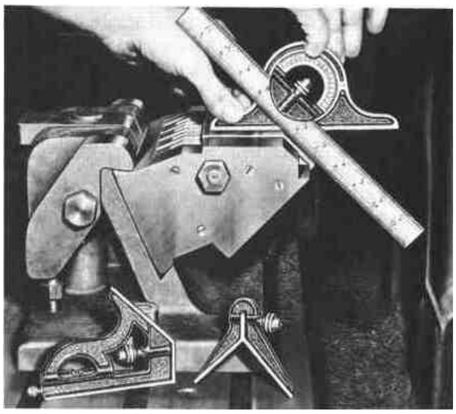


Fig. 7. Measuring an angle with a protractor head.

A **protractor head** is used to test, measure, or lay out angles to within 1° accuracy, fig. 7. The head may be graduated from 0° to 90° or from 0° to 180° in either direction. Some protractor heads, called the **nonreversible type,** have a shoulder extending from one side of the blade only. A second type, the **reversible type,** has a shoulder on both sides for measuring from either side.

A **steel square** is a precision tool, which is used when extreme accuracy is required. It is used for laying out lines or for testing the squareness of two surfaces with each other. Since it has no movable parts, it is extremely accurate. Compared to other types of squares, it is expensive. It is available in several sizes. The steel square is widely used by toolmakers and machinists for checking work on both surface plates and machine tools. Although it is hardened and tempered, the steel square should be handled carefully. Dropping or severe abuse may spoil its accuracy.

A **universal bevel protractor** equipped with a vernier, fig. 8, measures angles accurately to 5 minutes or one-twelfth of a degree. This tool also is called a **vernier protractor.** It may be used to lay out, measure, or check angles. A 150 or 300 mm blade may be inserted in the graduated dial and locked in position with the blade clamp nut. The blade and dial are swiveled to the angle desired, and the dial is locked with the dial clamp nut. An acute-angle attachment is provided for use in measuring angles of less than 90°.

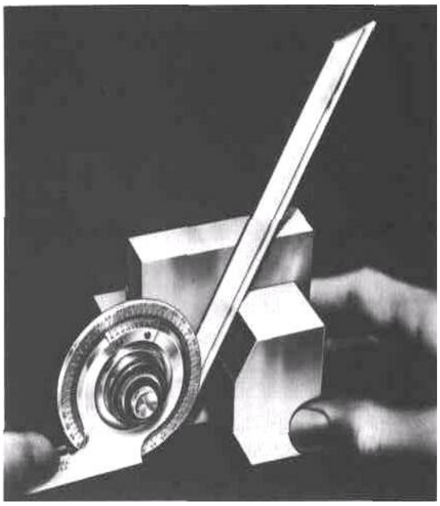


Fig. 8. A universal bevel protractor.

The protractor dial is graduated 360°, reading in whole degrees from 0 to 90, 90 to 0, 0 to 90, and 90 to 0. Each 10 degrees is numbered, and a long graduation divides each 5 degrees. The vernier plate is graduated with 12 spaces. Thus, each line here represents 5 minutes or one-twelfth of a degree. Every third line on the vernier plate is numbered to represent 15, 30, 45, and 60 minutes. Both the protractor dial and the vernier plate have numbers in both directions from zero.

When angles are read in whole degrees, the zero line on the vernier plate coincides with a graduation line on the protractor dial. Also, the graduation for 60 minutes will coincide exactly with a graduation on the dial. When angles are read which are not in whole degrees, the following procedure is used. Note how many degrees can be read from the zero line on the dial up to the zero line on the plate. Then, reading in the **same direction** (and this is important) note the number of minutes indicated by the line on the vernier which coincides exactly with a line on the dial. Add this amount to the number of whole degrees. Remember, each graduation line on the vernier represents 5 minutes.

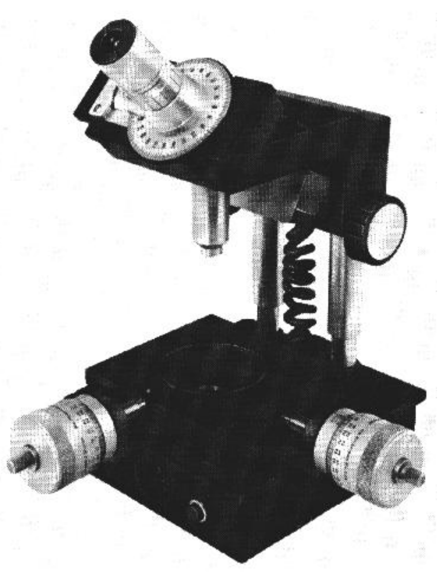


Fig. 9. Toolmaker's microscope.

The **toolmaker's microscope** is designed especially for use in toolmaking (fig. 9). Angles can be measured with anguler microscope head (or **microscope head**) with accuracy 1′. Images can be enlarged from 10 to 200 times, depending on equipment and job requirements. Images are not reversed as in ordinary microscopes. The platform, called a **stage,** on which workpieces are mounted for measurement, can be moved both crossways and sideways with vernier micrometer accuracy. A **vernier protractor** built into the microscope head, reads to **one minutes** (or only 5 minutes sametimes) of arc through the magnifying lens. The microscope optics provide 90° cross hairs and concentric circles with diameters from 0.25 - 5 mm by 0.25 mm. An attachment allows cylindrical workpieces to be supported between centers. Direct angular measurement, thread dimensions, radius, hole roundness, and even squareness can be easily checked with a high degree of accuracy.

An **optical comparator** projects an accurately enlarged shadow-like profile of the part being measured into a screen. Here, both its size and shape are compared to a master drawing or template. Magnification of 10, 20, and 50 diameters are commonly used. A stage provides sideways and crossways movement of the part to vernier micrometer accuracy. Angular measurement can be directly from templates or from a protractor attachment. Optical comparators are especially useful for checking small, irregularly shaped objects which cannot be easily measured with conventional tools. Flexible parts, such as springs and rubber or plastic objects, which would distort under the pressure of conventional measuring tools, can easily be inspected. The accuracy of thread forms, gear tooth shape, and cam profiles are easily checked in this manner.

The **sine bar** is a precision tool used to establish or check angles to within one minute of arc (fig. 10). Sine bars must be used in conjunction with some true surface, such as a surface plate, from which accurate measurements may be taken.

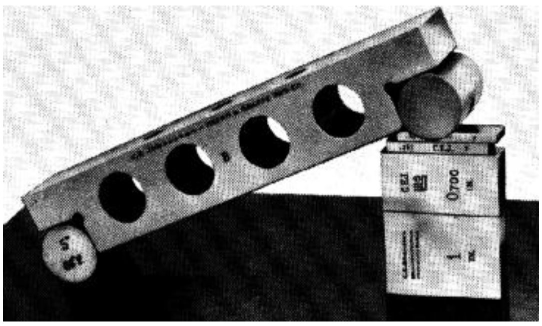


Fig. 10. A sine bar.

They are used to establish and check angles for layout work and inspection work. They may be used for making machining setups such as those often required for surface grinding. They also may be used to accurately determine unknown angles.

The sine bar is a hardened and precision-ground steel bar which has two hardened and precision-ground steel rolls of the same diameter attached. The edge of the bar is parallel with the center line of the rolls. For convenient mathematical calculation, it is available in lengths which provide a distance of 127 mm, 254 mm, or 508 mm (5", 10", or 20") between the centerlines of the rolls.The sine bar is named after the sine trigonometry function, which states that the sine of an angle is equal to the length of the side opposite the angle divided by the length of the hypotenuse. Either unknown angle α can be found when the side **a** opposite the angle, and the hypotenuse **c** are known: $\sin\alpha = a/c$.

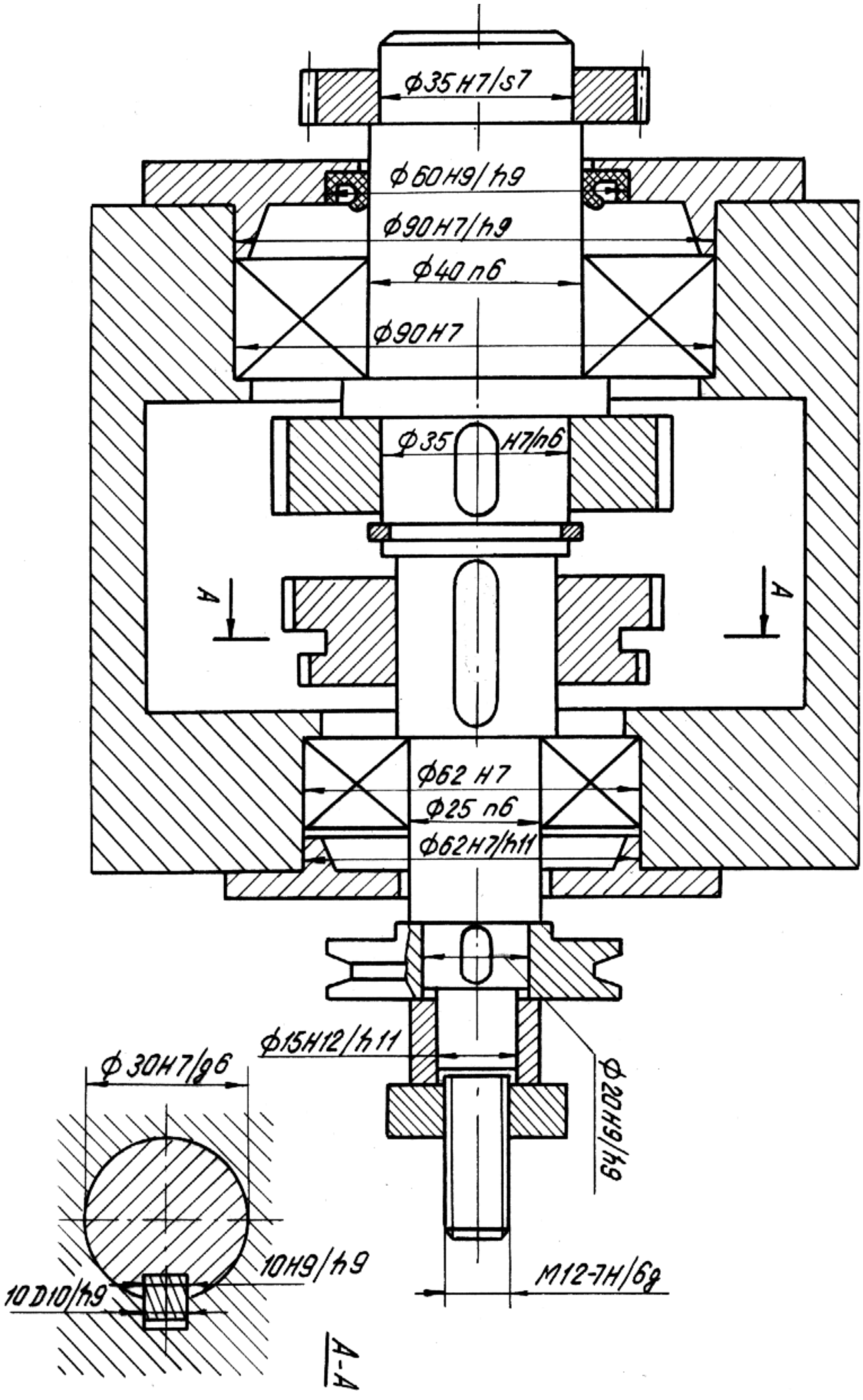


Fig. 11. An assembly drawing.

A division of a measuring tool (responsibility) has to be from 5 to 10 times less than the size tolerance of the measured part. For example, for $50_{-0.3}$ mm a division has to be 0.05…0.03. That is why we can use a veirnier caliper (with a division of 0.05 mm) or micrometer (with a division of 0.01 mm, range of 25 – 50 mm).

6. Order of performing work

1. Write down the designations of the **rolling contact bearing fits** for the diameter of 30 mm. Draw all tolerance zones for all fits. Determine the limit clearances or interferences.
2. Draw tolerance zones for the fit with the diameter of 30 mm with $S_{max}<[S_{max}]=18$ μm and $S_{min}> [S_{min}]=8$ μm. But we can produce parts with the tolerance T=15 μm. Determine the limit clearances or interferences.
3. Draw tolerance zones for the fit with the diameter of 30 mm with $N_{max}<[N_{max}]=18$ μm and $N_{min}> [N_{min}]=8$ μm. But we can produce parts with the tolerance T=15 μm. Determine the limit clearances or interferences.
4. Draw tolerance zones for the **key fit** of the shaft with the diameter of 30 mm. Draw an assembly drawing and all views or cross sections. Write down all fits. Determine the limit clearances or interferences.
5. Draw tolerance zones for the **moveable slit junctions** with external diameter of 30 mm. Draw an assembly drawing and all views or cross sections. Write down all fits. Determine the limit clearances or interferences.
6. Draw tolerance zones for the **conical junction** with a large diameter of 30 mm and a length 40 mm. It is necessary to transmit loading 10 Nm with a gear wheel.
7. Write down the names of all measuring instruments required for inspection of size and angles.

Laboratory work №5
“Measurements of limit plug gages”

The purpose of work:

1. To make students acquainted with the equipment and methods of measurement of external and internal sizes with limit plug gages.
2. To help students acquire elementary skills of experimental research work when carrying out laboratory work.
3. To study the basic operations of external and internal sizes inspection.
4. To acquire skills of defining the tolerance zones of limit plug gages.
5. To acquire skills of defining the metrological characteristics of measuring devices.
6. To skills of plug gage measurements and define their validity (usefulness).

The equipment and materials:

1. Optimeter.
2. Microcator.
3. Minimeter.
4. Gage blocks.
5. Limit plug gages.

A tolerance-limit gage is often referred to as a "**go** and **no-go**" gage. These gages are generally accepted as the most practical, accurate, and economical method of inspecting production tolerances. They check given dimensions by direct physical contact. **Go** and **no-go** (sometimes **not-go**) gages are built in wide variety of designs depending upon use. Go and not-go gages are also called **limit gages.** Because they have two gauging surfaces or points, they sometimes also are called **double gages.** One gauging surface is used for testing the upper size limit; the other - the lower size limit. Most such gages are labeled "go" and "not go", meaning that the part will **go** at the first point, but it will **not go** at the second.

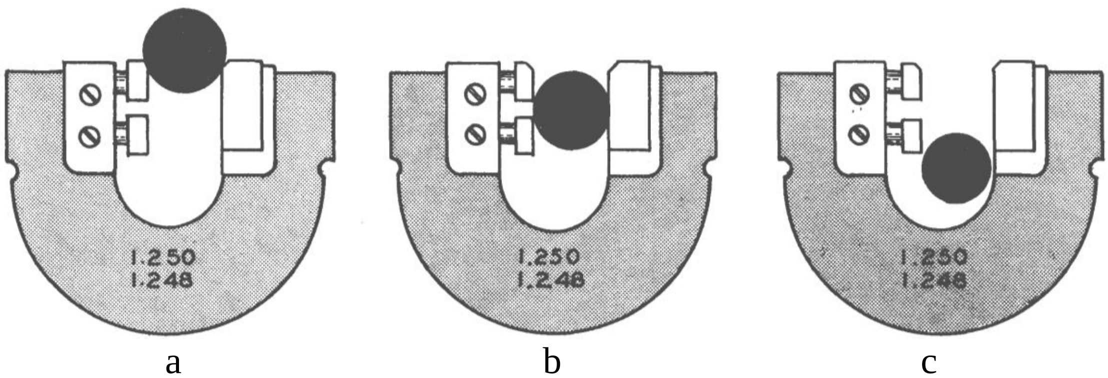


Fig. 1. Parts checked in a limit gage: a) part is too large; b) part is satisfactory; c) part is undersize.

Limit gages never should be forced under high pressures when checking parts. The pressures applied to the gauging surfaces should be slight. Limit gages have contact surfaces which are hardened, precision-ground, and lapped. Although they are designed for accuracy and wear resistance, they should be handled and used carefully. Snap gages, ring gages, and plug gages are the most common.

The **snap gage** is a limit gage available in several styles and sizes. The one shown has one stationary anvil and two button anvils which are adjustable (fig.1, 2). This caliper-type gage is used to gauge thicknesses, lengths, and outside diameters. In operation the outer button is set to the **go** size and the inner button to **no-go**.

Gage blocks can be used to set the size limits on a snap gage. The principle involved in testing cylindrical parts with a limit snap gage is shown in the drawing (fig. 1). The upper gaging point is the go point, while the lower is the no-go point. If the part does not pass through the go point (it will hang on the upper gauging point (fig. 1, a), the work is too large (oversize). If it passes through the go point, but not the no-go, the work is satisfactory (fig. 1, b). If it passes the go point and the no-go point, the work is undersize (fig. 1, c).

Fig. 2. Adjustable limits snap gage.

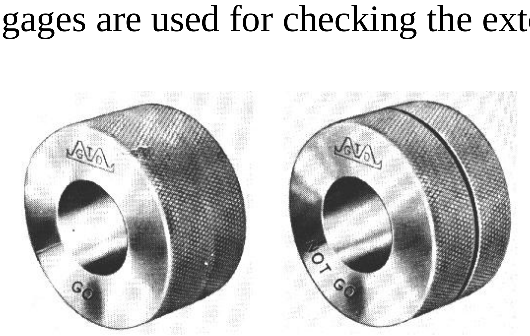
The reverse applies to inside measurements.

The size limits on a snap gage may be checked with gage blocks or with accurate measuring devices (such as horizontal optimeter). Limits snap gages may be supplied by the manufacturer set and **sealed** at specified size limits, or **unset** and **unsealed** (fig. 2). When preset, the adjustment screws usually are sealed with sealing wax and the size limits are stamped on the gage.

Snap gages of special types are fitted with special anvils, buttons, or rolls for gauging special forms or external threads. A roll thread snap gage is used to check the size limits for the pitch diameter of screw threads.

Three types of **ring gages** are commonly used for checking the external diameters of parts: plain ring gages, taper ring gages, and thread ring gages.

Plain ring gages (fig. 3) are designed in the form of a cylindrical ring. These gages are used for checking the external diameters of straight round parts. The **not-go** ring (identified by the groove around the outside diameter, fig. 3, b) is used to check the minimum size limit. The **go** ring is used to check the maximum size limit. The **go** ring will pass over a part which is within specified size limits with little or no interference. The **not-go** ring will not pass over the work. If both rings pass over, the part is undersize. If neither does, the part is oversize.



a b

Fig. 3. Plain ring gages.

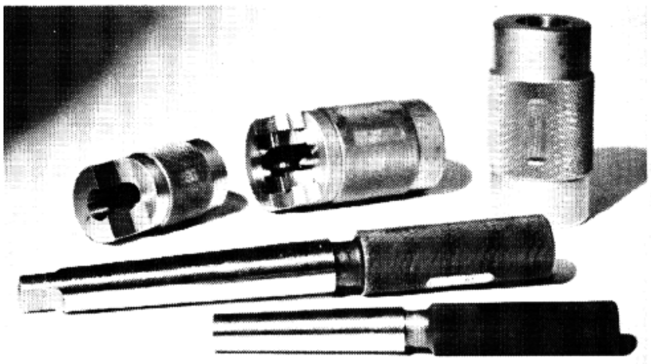
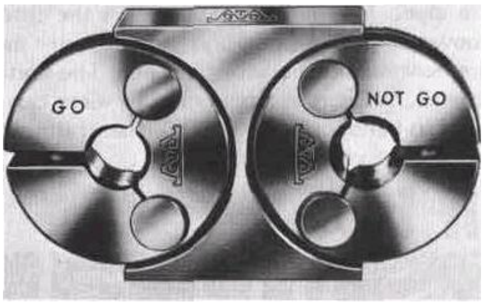


Fig. 4. Cylindrical taper ring and plug gages.

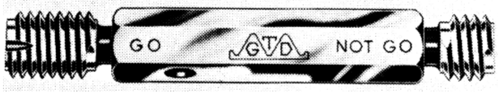
Taper ring gages (fig. 4) are used for checking the size and the amount of external cylindrical taper on parts. Cylindrical taper ring gages are used for checking the taper shanks on drills, reamers, lathe centers, and other machine accessories.

In using a taper ring gage, first **draw three equally spaced chalk lines** lengthwise on the external tapered surface which is to be checked. Then slip the ring over the external taper by applying a light pressure for good surface contact.

Rotate the ring forward and backward a small amount while continuing to apply light pressure. Remove the gage and observe the external tapered surface. If all three chalk lines have been uniformly rubbed and distributed, the taper is correct. If the chalk lines have been rubbed harder at one end than at the other, then a correction should be made on the taper. The correct amount of taper should be established before the part is machined to finished size. Size may be determined by measuring the small diameter with a micrometer or by noting the distance to which the taper enters the ring gage.



a



b

Fig.5. Thread ring (a) and plug (b) gages.

Thread ring gages of the go and not-go type are used for checking the pitch diameter of external threads (fig. 5, a). **Thread plug gages** of the go and not-go type are used for checking the pitch diameter of internal threads (fig. 5, b).

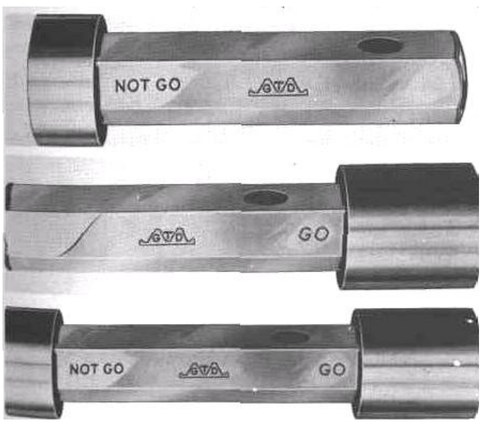


Fig. 6. Plain cylindrical plug gages. Top — single-end gages. Bottom — double-end gage.

Three basic types of **plug gages** are used for checking the accuracy of holes: plain cylindrical plug gages, cylindrical taper plug gages, and thread plug gages. Plug gages of special types also are available for use in checking holes of a special shape, such as square holes and rectangular holes.

Plain cylindrical plug gages (fig. 6) are accurate cylinders which are used for checking the size limits of straight cylindrical holes. The gage is provided with a handle for convenient use. The gage may be either the single-end type or the double-end type. The go gage is longer than the not-go gage; it should enter the hole with little or no interference. If great pressure is required, the hole is undersize and is not acceptable. The not-go gage should not enter the hole. If it does, the hole is too large.

A **progressive-type plug gage** has both the go and the not-go gages **on the same end** of the handle. It is efficient for checking through holes, but it cannot be used for shallow, blind holes.

Tapered cylindrical plug gages (fig. 4) are used for checking the size and amount of taper in tapered cylindrical holes in drill sleeves, in machine tool spindles, and in adapters for use with taper shank tools. In using the tapered cylindrical plug gage to check a tapered hole, use the same procedure described above for using a tapered cylindrical ring gage. The hole is finished to size when the gage enters to the end of the plug or to a depth indicated by the line around the outside diameter on the gage.

Thread plug gages are used for checking the size limits for the pitch diameter of internal screw threads (fig. 5, b).

Tolerances zones of limit gages

The principles involved in testing a hole with gages are illustrated in fig. 7.

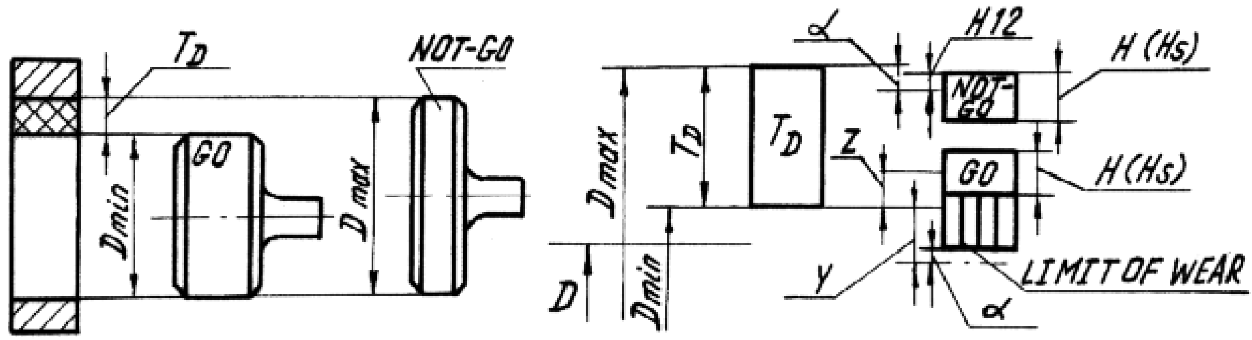


Fig. 7. A scheme of gages tolerances zones for testing a hole.

We have to make a gage with the size equal to D_{max}. If the size of the hole is smaller than D_{max} (a good size) this gage will not go through this hole. If the size of the hole is larger then D_{max} (a bad size) this gage will go through this hole. These gages do not go through a good hole, that is why they are called **Not-Go** gages.

We have checked only the upper limit of the hole tolerance zone. Then we are to check a lower limit. We make the size of the gage equal to the lower possible size of the hole (D_{min}). If the size of the hole is larger than D_{min} (a good size) this gage will go through this hole. These gages go through a good hole, that is why they are called **Go** gages. If the size of the hole is smaller than D_{min} (a bad size) this gage will not go through this hole.

Of course, we can not make gages absolutely exactly. That is why we nominate the tolerance of the gage **H** using the standard for gages. The **Go** gage will often go, that is why the gage tolerance zone is increased by **z** and the possible wear size is reduced by **y** in order to increase work life of the gage.

It should be noted that the points of count for gage deviations are tolerance zone limits of the part.

The principles involved in testing shafts with gages are the same as for holes and are illustrated in fig.8. If the size of the shaft is smaller than d_{max} (a good size) that gage is made with size equal to d_{max} and will go through this hole. If the size of a shaft is larger than d_{max} (a bad size) that gage will not go through this hole. These gages go through good shafts that is why they are called **Go** gages.

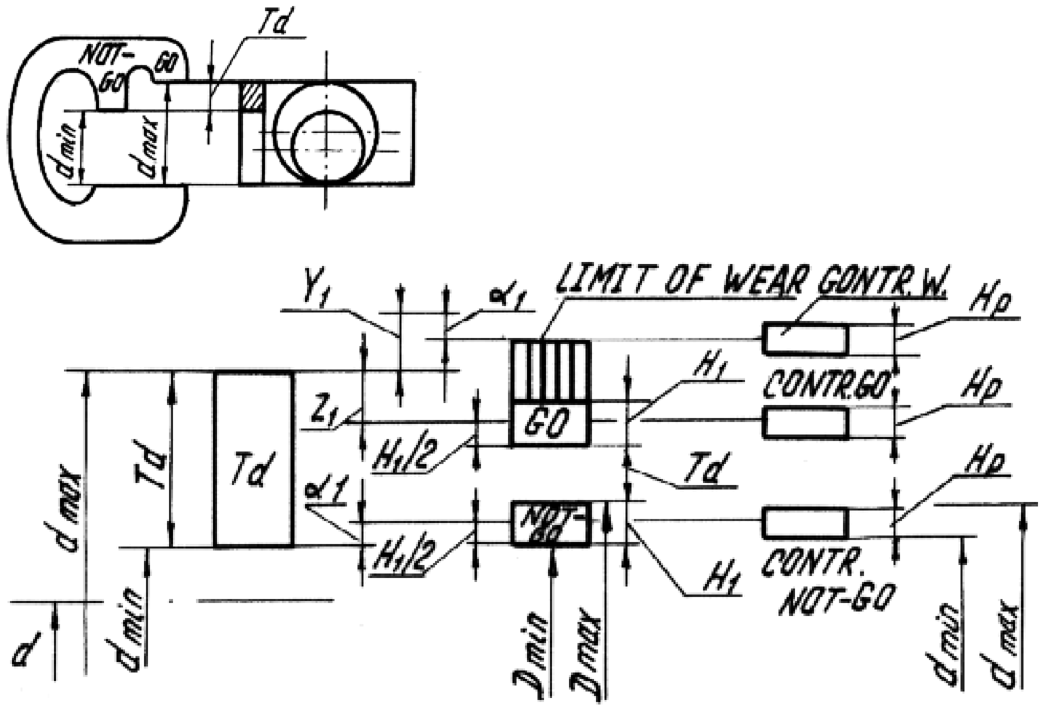


Fig. 8. A scheme of gages tolerance zones for testing a shaft.

We have checked only the upper limit of the shaft tolerance zone. Then we are to check a lower limit. We make the size of the gage equal to the lower possible size of the shaft (d_{min}). If the size of the shaft is larger than d_{min} (a good size) this gage will not go through this hole. These gages do not go through good shafts that is why they are called **Not-Go**.

Value α is equal to **0** for the basic size which is **smaller** than 180 mm.

The ***advantages of gages*** are:

1. Short time required for inspection process.
2. Easy inspection.

The ***disadvantages*** are:

1. Only a definite size can be tested.
2. High cost.

Table 1. Tolerance of gages, μm.

Grade of tolerance	Symbol	Basic size, mm							
		1 - 3	3 - 6	6 - 10	10 - 18	18 - 30	30 - 50	50 - 80	80- 120
6 gr.	z	1	1.5	1.5	2	2	2.5	2.5	3
	y	1	1	1	1.5	1.5	2	2	3
	z_1	1.5	2	2	2.5	3	3.5	4	5
	y_1	1.5	1.5	1.5	2	3	3	3	4
	H, H_s	1.2	1.5	1.5	2	2.5	2.5	3	4
	H_1	2	2.5	2.5	3	4	4	5	6
	H_p	0.8	1	1	1.2	1.5	1.5	2	2.5
7 gr.	z, z_1	1.5	2	2	2.5	3	3.5	4	5
	y, y_1	1.5	1.5	1.5	2	3	3	3	4
	H, H_1	2	2.5	2.5	3	4	4	5	6
	H_s	---	---	1.5	2	2.5	2.5	3	4
	H_p	0.8	1	1	1.2	1.5	1.5	2	2.5
8 gr.	z, z_1	2	3	3	4	5	6	7	8
	y, y_1	3	3	3	4	4	5	5	6
	H	2	2.5	2.5	3	4	4	5	6
	H_1	3	4	4	5	6	7	8	10
	H_s, H_p	1.2	1.5	1.5	2	2.5	2.5	3	4
9 gr.	z, z_1	5	6	7	8	9	11	13	15
	y, y_1	0	0	0	0	0	0	0	0
	H	2	2.5	2.5	3	4	4	5	6
	H_1	3	4	4	5	6	7	8	10
	H_s, H_p	1.2	1.5	1.5	2	2.5	2.5	3	4

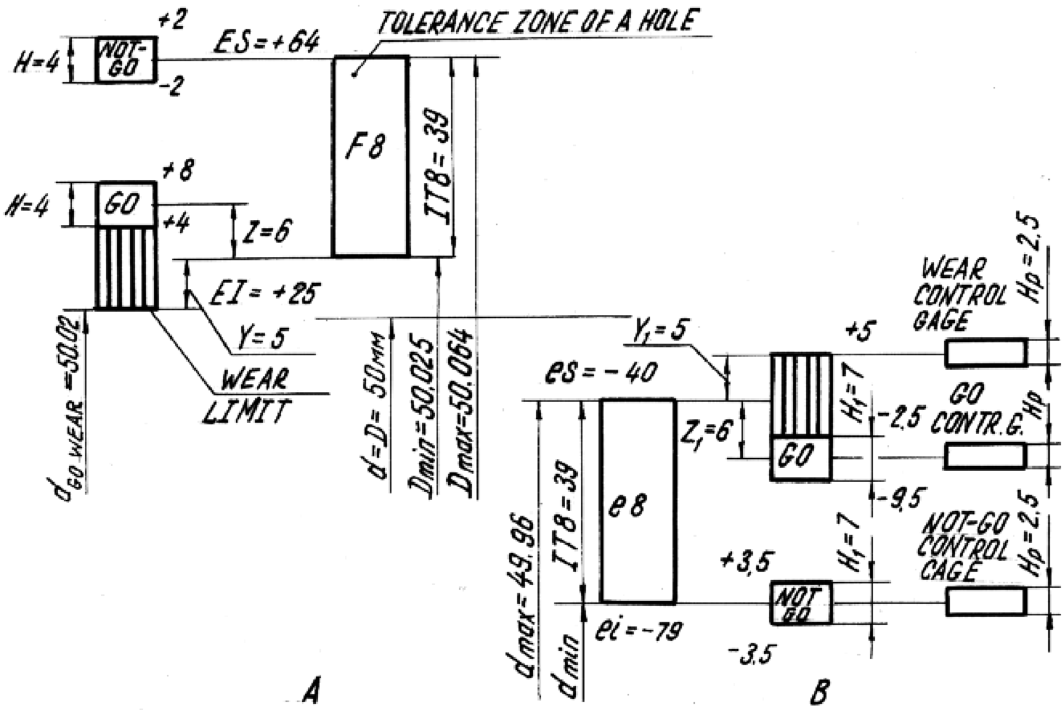


Fig. 9. A scheme of gages tolerance zones for testing the hole 50F8 and the shaft 50e8.

Order of performing work

1. Write down the designation of the given limit plug gage.
2. Write down the designation of the **hole** checked with the given limit plug gage, draw the tolerance zone of the hole and define deviations.
3. Write down the designation of the **not-go** gage, draw the tolerance zone of the gage and define deviations. Write down the gage deviations with different forms: symmetrical, a “shaft”, “hole”. Choose the preferable form.
4. Write down the designation of the **go** gage, draw the tolerance zone of the gage and define deviations. Write down the gage deviations with different forms: symmetrical, a “shaft”, a “hole”. Write down the preferable form.
5. Write down the designation of the **wear go** gage, draw the tolerance zone of the gage and define deviations. Write down the preferable form of the gage deviations.
6. Write down the **set of gage blocks** used for adjustment of measuring devices.
7. Write down the designation of the measuring devices, **metrological characteristics** (division, ranges of the scale and device).
8. Write down the adjusted size, readings of adjustment $\mathbf{S_A}$ and measurement $\mathbf{S_M}$, relative transference $\mathbf{\Delta_R}$, general dimension $\mathbf{d_r}$. Compare the measured dimension with the limit sizes of the checked gage and write down the conclusion of validity (usefulness).
9. Repeat measurements with other devices (items 7 and 8). Write down conclusions of validity on each device.
10. Write down a general conclusion of the gage validity.

Laboratory work №6
"Measurement of screw threads"

The purpose of work:
1. To get acquainted with the choice of screw thread fits.
2. To get acquainted with the technical requirements and characteristics of fixing.
3. To get acquainted with the equipment and methods of inspection of screw diameters.
4. To estimate the accuracy of controlled parts and write the accordance designations.

Equipment:
1. Big toolmaker's microscope.

1. The basic rules on the theme of work

A screw thread is a helical or spiral ridge of a uniform section on the surface of a cylinder or a cone, either external or internal. Threads on bolts and screws are **external threads**, fig. 1. Threads on nuts are **internal threads**, fig. 2. External threads and internal threads have the same basic pitch diameters. Threads on a cylindrical surface (such as bolts, machine screws, and nuts) are **straight** or **parallel** threads. Threads on a conical surface are **tapered** threads.

Threads may be **right-hand** (RH) or **left-hand** (LH). A right-hand thread advances away from the observer when turned clockwise. A left-hand thread advances away from the observer when turned counterclockwise. A grinder with two grinding wheels, one mounted on each end of the arbor, has a right-hand thread and nut on one end and a left-hand thread and nut on the other end. Taps and dies are available for use in cutting right-hand and left-hand threads. Unless a thread is otherwise designated, it is assumed to be right-hand.

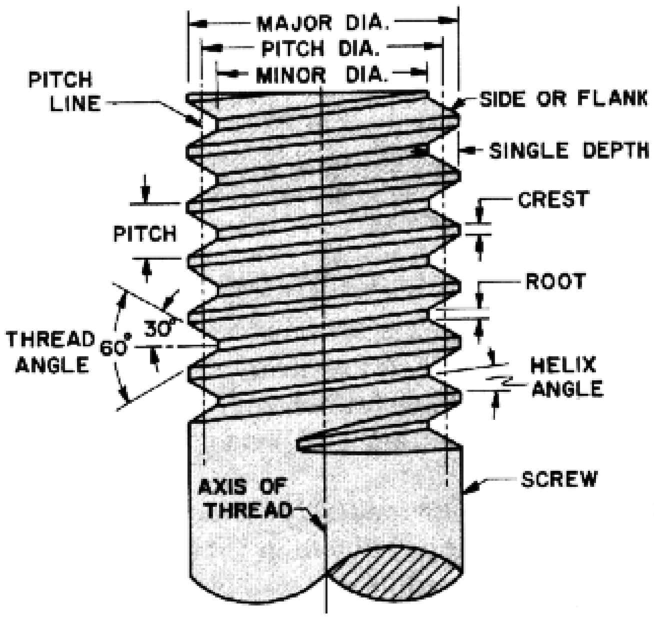


Fig. 1. Principal parts of an external screw thread.

Screw threads are widely used on fasteners such as nuts, bolts, and screws. They permit easy assembly and dismantling for replacement of parts.

Screw threads are also widely used to transmit motion, transmit power, increase mechanical advantage, control movement accurately and uniformly, and permit adjustments on machines. The lead screw on a lathe transmits power. The screw on a vise provides for increasing mechanical advantage. The screw on a micrometer provides accurate and uniform control of movement, thus making accurate measurement possible. Screw threads allow for adjustments on tools, machines, instruments, and control devices.

Major diameter: the largest diameter of a straight external or internal thread, fig. 1. **Minor diameter:** the smallest diameter on a straight external or internal screw thread. **Pitch diameter:** on a straight thread, the diameter of an imaginary cylinder which passes through the thread profile at points where **the width of the groove and the width of the thread are equal**. The pitch diameter may be measured with a thread micrometer. The amount of clearance permitted between two mating threads is controlled by maintaining close tolerances on their pitch diameters.

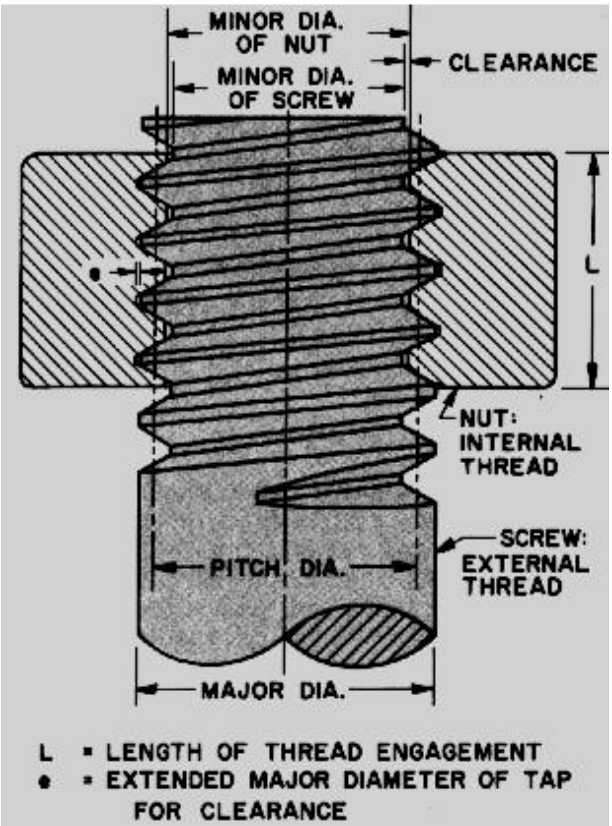


Fig. 2. Comparison between the minor diameters of a screw and a nut, showing clearance.

The pitch diameter on a taper thread, at a given position on the thread axis, is the diameter of the pitch cone at that position.

Pitch: the distance from a point on one screw thread to a corresponding point on the adjacent thread, measured parallel to the thread axis. The pitch of a thread is a measure of the size of the thread form. For metric threads, the pitch is expressed in millimeters. For inch-based threads, the pitch is equal to 1 divided by the number of threads per inch.

Lead: the distance a thread moves along its axis, with respect to a mating part, in one complete revolution. On a single thread, the lead and the pitch are the same. On a double thread, the lead is equal to twice the pitch. On a triple thread, the lead is equal to three times the pitch, fig. 3. A single thread has

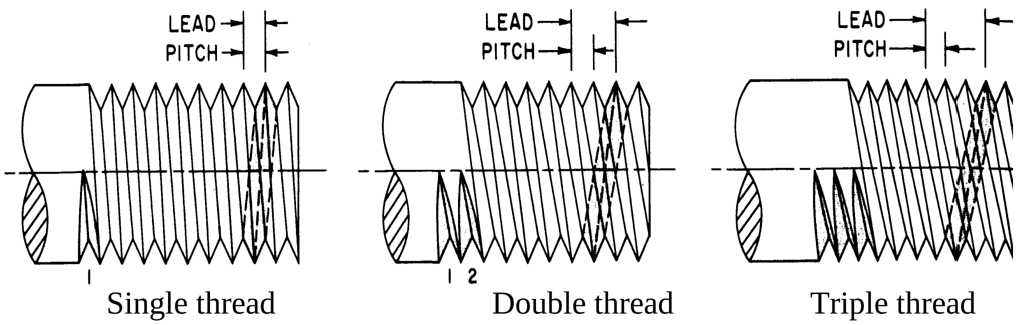


Fig. 3. Relationship of pitch and lead on multiple threads.

one groove; a double thread, two grooves; a triple thread, three grooves; and so on. **Multiple thread:** a thread having the same form produced with two or more helical grooves, such as a double, triple, or quadruple thread, fig. 2.

Angle of thread (α): the included angle between the sides of the flanks of the thread measured in the axial plane, fig. 1. For **metric threads** the angle of a thread is equal to **60º**.

Lead angle ψ (sometimes called helix angle)**:** an angle made by the helix of a thread at the pitch diameter measured in a plane perpendicular to the axis of the thread.

Axis of a screw thread: the axis of the pitch cylinder or cone on which a screw thread appears.

Crest: the top surface which joins the two sides of a thread. The crest of an external thread is at its major diameter. The crest of an internal thread is at its minor diameter, fig. 1.

Root: the bottom surface which joins the sides of two adjacent threads. The root of an external thread is at its minor diameter. The root of an internal thread is at its major diameter, fig. 1.

Flank: the surface which connects the crest with the root on either side of the thread, fig. 1.

Clearance (S): the distance between the crest of a thread and the root of the mating thread, measured perpendicular to the thread axis, fig. 2.

Depth of engagement: the depth to which one thread is engaged with a mating thread measured perpendicular to the thread axis.

Length of engagement: the contact distance between an external and internal thread measured parallel to the axis along the pitch cylinder or cone, fig. 2.

Height of thread (sometimes called the depth of the thread)**:** the distance between the major and minor cylinders or cones of a thread measured perpendicular to the axis of the thread.

Form: the profile for the length of one pitch in the axial plane, fig. 4.

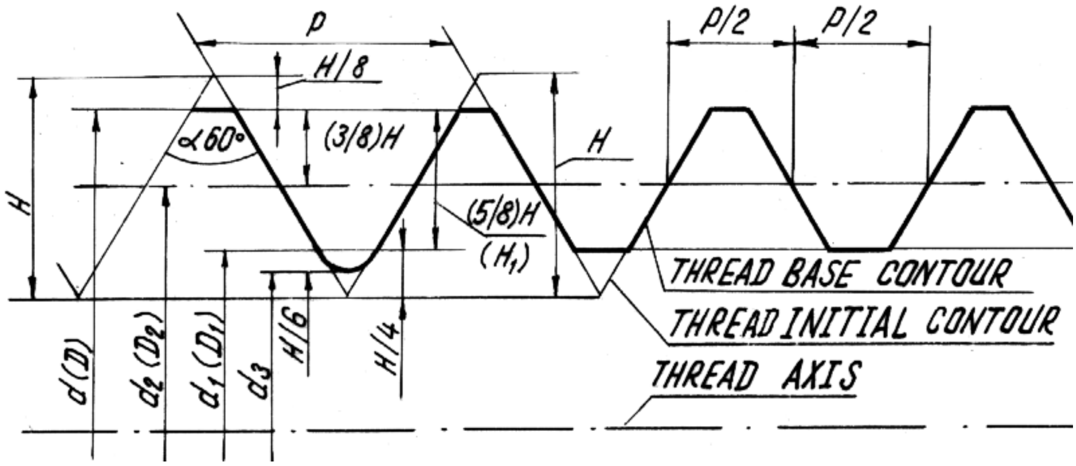


Fig. 4. Cross section of a thread form.

Maximum material limits: the maximum limit of size for an external dimension, or the minimum limit of size for an internal dimension.

Minimum material limits: the minimum limit of size for an external dimension, or the maximum limit of size for an internal dimension.

Table 1. Tolerance grades for ISO Metric threads.

External Thread		Internal Thread	
Major Diameter	Pitch Diameter	Major Diameter	Pitch Diameter
	3		
4	4	4	4
	5	5	5
6	6	6	6
	7	7	7
8	8	8	8
	9		

Basically, there are three classes of fit: **fine, medium,** and **coarse.** The classes of fit are more accurately identified by specification of the **tolerance grade** and **tolerance position** of the mating external and internal threads. Tolerance grades are specified by a number, and may be applied to both the major diameter and pitch diameter. Table 1 lists the range of tolerance grades for external and internal threads. Grade 6 is recommended for medium fits on general purpose threads, and is closest to Unified class 2A and 2B fits.

Tolerance position is specified with a **lowercase letter for external threads**, and a **capital letter for internal threads** as follows:

External threads: e - large allowance; g - small allowance; h - no allowance.

Internal threads: G - small allowance; H - no allowance.

The combination of tolerance grade and tolerance position constitutes the **tolerance class** of the thread. Fine - 5H/4h; medium -6H/6g; coarse - 7H/8g. Generally coarse tolerance class **7H/6g** is used.

Table 2. Basic diameters and pitches of Metric thread for rows 1 and 2.

Basic major diameter, mm		Pitch P, mm		Basic diameter, mm		Pitch, mm	
Row 1	Row 2	**Large**	Small	**Row 1**	Row 2	**Large**	Small
3		**0.5**			33	**3.5**	2; 1.5
4		**0.7**	0.5	**36**		**4**	3; 2; 1.5
5		**0.8**	0.5		39	**4**	3; 2; 1.5
6		**1**		**42**		**4.5**	3; 2; 1.5
8		**1.25**	1		45	**4.5**	3; 2; 1.5
10		**1.5**	1.25; 1	**48**		**5**	3; 2
12		**1.75**	1.5; 1.25		52	**5**	3; 2
	14	**2**	1.25	**56**		**5.5**	4; 3
16		**2**	1.5		60	**---**	4; 3
	18	**2.5**	2; 1.5	**64**		**6**	4; 3
20		**2.5**	2; 1.5		68	**6**	4; 3
	22	**2.5**	2; 1.5	**72**		**---**	6; 4; 3
24		**3**	2; 1.5		76	**---**	6; 4; 3
	27	**3**	2; 1.5	**80**		**---**	6; 4; 3
30		**3.5**	2; 1.5		85	**---**	6; 4; 3
				90		**---**	6; 4; 3

Table 3. Value of basic pitch and minor diameters of Metric thread.
(ISO 68 and ISO R1501-1970.)

Pitch P, mm	Basic diameters of a thread		Pitch P, mm	Basic diameters of a thread	
	Pitch diameter d_2 and D_2	Minor diameter d_1 and D_1		Pitch diameter d_2 and D_2	Minor diameter d_1 and D_1
0.075	d - 1 + 0.951	d - 1 + 0.919	0.7	d - 1 + 0.546	d - 1 + 0.242
0.08	d - 1 + 0.948	d - 1 + 0.913	0.75	d - 1 + 0.513	d - 1 + 0.188
0.09	d - 1 + 0.942	d - 1 + 0.903	0.8	d - 1 + 0.480	d - 1 + 0.134
0.1	d - 1 + 0.935	d - 1 + 0.892	1	d - 1 + 0.350	d - 2 + 0.918
0.125	d - 1 + 0.919	d - 1 + 0.865	1.25	d - 1 + 0.188	d - 2 + 0.647
0.15	d - 1 + 0.903	d - 1 + 0.838	1.5	d - 1 + 0.026	d - 2 + 0.376
0.175	d - 1 + 0.886	d - 1 + 0.811	1.75	d - 2 + 0.863	d - 2 + 0.106
0.2	d - 1 + 0.870	d - 1 + 0.783	**2**	**d - 2 + 0.701**	**d - 3 + 0.835**
0.225	d - 1 + 0.854	d - 1 + 0.756	2.5	d - 2 + 0.376	d - 3 + 0.294
0.25	d - 1 + 0.838	d - 1 + 0.730	3	d - 2 + 0.051	d - 4 + 0.752
0.3	d - 1 + 0.805	d - 1 + 0.675	3.5	d - 3 + 0.727	d - 4 + 0.211
0.35	d - 1 + 0.773	d - 1 + 0.621	4	d - 3 + 0.402	d - 5 + 0.670
0.4	d - 1 + 0.740	d - 1 + 0.567	4.5	d - 3 + 0.077	d - 5 + 0.129
0.45	d - 1 + 0.708	d - 1 + 0.513	5	d - 4 + 0.752	d - 6 + 0.587
0.5	d - 1 + 0.675	d - 1 + 0.459	5.5	d - 4 + 0.428	d - 6 + 0.046
0.6	d - 1 + 0.610	d - 1 + 0.350	6	d - 4 + 0.103	d - 7 + 0.505

Table 4. Fundamental deviations of Metric thread.
(ISO 68 and ISO R1501-1970.)

Pitch P, mm	Fundamental deviation of a thread, μm								
	External thread (**es** for d, d_2, d_1.)					Internal thread (**EI** for D_1, D_2, D.)			
	d	e	f	g	h	E	F	G	H
0.5	---	-50	-36	-20	0	+50	+36	+20	0
0.7	---	-56	-38	-22	0	+56	+38	+22	0
0.8	---	-60	-38	-24	0	+60	+38	+24	0
1	-90	-60	-40	-26	0	+60	+40	+26	0
1.25	-95	-63	-42	-28	0	+63	+42	+28	0
1.5	-95	-67	-45	-32	0	+67	+45	+32	0
1.75	-100	-71	-48	-34	0	+71	+48	+34	0
2	**-100**	**-71**	**-52**	**-38**	**0**	+71	+52	+38	0
2.5	-106	-80	-58	-42	0	+80	---	+42	0
3	-112	-85	-63	-48	0	+85	---	+48	0
3.5	-118	-90	---	-53	0	+90	---	+53	0
4	-125	-95	---	-60	0	+95	---	+60	0
4.5	-132	-100	---	-63	0	+100	---	+63	0
5	-132	-106	---	-71	0	+106	---	+71	0
5.5	-140	-112	---	-75	0	+112	---	+75	0
6	-150	-118	---	-80	0	+118	---	+80	0

Basic designations for all ISO Metric threads begin with the capital letter "M". Next, the nominal size (basic major diameter) in millimeters is given. This is followed by the pitch in millimeters separated by an "×". ISO practice calls for the pitch to be omitted when designating coarse series threads. Therefore, an ISO Metric 10 mm coarse series thread with a pitch of 1.5 mm (large pitch) would simply be designated M10, whereas the same diameter in the fine series would be designated M10×1.25. See table 2.

Complete designations for ISO Metric threads include identification of the tolerance class. The tolerance class follows the basic designation separated by a dash. The tolerance grade and position for the pitch diameter are given first, followed by the tolerance grade and position for the major diameter. If the pitch and major diameter tolerance are the same, then the symbols need only be given once.

Examples: M10×1.25-6g8g, where 6g- tolerance class of a pitch diameter tolerance symbol; 8g- tolerance class of a major diameter tolerance symbol. 6 or 8- tolerance grade, g- tolerance position.

M16×1.5-6g , - tolerance grade and position for both pitch and major diameter are identical.

Table 5. Tolerances for major and minor diameters of Metric thread.
(ISO 68 and ISO R1501-1970.)

Pitch P, mm	Td for **external** thread, μm			TD_1 for **internal** thread, μm				
	Tolerance grade							
	4	6	8	4	5	6	7	8
0.5	67	106	---	90	112	140	180	---
0.7	90	140	---	112	140	180	224	---
0.8	95	150	236	125	160	200	250	315
1	112	180	280	150	190	236	300	375
1.25	132	212	335	170	212	265	335	425
1.5	150	236	375	190	236	300	375	475
1.75	170	265	425	212	265	335	425	530
2	180	280	450	236	300	375	475	600
2.5	212	335	530	280	335	450	560	710
3	236	375	600	315	400	500	630	800
3.5	265	425	670	355	450	560	710	900
4	300	475	750	375	475	600	750	950
4.5	315	500	800	425	530	670	850	1060
5	335	530	850	450	560	710	900	1120
5.5	335	560	900	475	600	750	950	1180
6	375	600	950	500	630	800	1000	1250

Table 6. Tolerances for pitch diameter of Metric external thread.
(ISO 68 and ISO R1501-1970.)

Basic diameter (d_2) of a thread, mm	Pitch P, mm	Td_2, μm, for the tolerance grade						
		3	4	5	6	7	8	9
2.8 - 5.6	0.5	38	48	60	75	95	---	---
	0.7	45	56	71	90	112	---	---
	0.8	48	60	75	95	118	150	190
5.6 - 11.2	1	56	71	90	112	140	180	224
	1.25	60	75	95	118	150	190	236
	1.5	67	85	106	132	170	212	265
11.2 - 22.4	1.25	67	85	106	132	170	212	265
	1.5	71	90	112	140	180	224	280
	1.75	75	95	118	150	190	236	300
	2	**80**	**100**	**125**	**160**	**200**	**250**	**315**
	2.5	85	106	132	170	212	265	335
22.4 - 45	1.5	75	95	118	150	190	236	300
	2	85	106	132	170	212	265	335
	3	100	125	160	200	250	315	400
	3.5	106	132	170	212	265	335	425
	4	112	140	180	224	280	355	450
	4.5	118	150	190	236	300	375	475
45 - 90	3	106	132	170	212	265	335	425
	4	118	150	190	236	300	375	475
	5	125	160	200	250	315	400	500
	5.5	132	170	212	265	335	425	530
	6	140	180	224	280	355	450	560

Table 7. Tolerances for pitch diameter of Metric internal thread.
(ISO 68 and ISO R1501-1970.)

Basic diameter (D_2) of a thread, mm	Pitch P, mm	TD_2, μm, for the tolerance grade				
		4	5	6	7	8
2.8 - 5.6	0.5	63	80	100	125	---
	0.7	75	95	118	150	---
	0.8	80	100	125	160	200
5.6 - 11.2	1	95	118	150	190	236
	1.25	100	125	160	200	250
	1.5	112	140	180	224	280
11.2 - 22.4	1.25	112	140	180	224	280
	1.5	118	150	190	236	300
	1.75	125	160	200	250	315
	2	132	170	212	265	335
	2.5	140	180	224	280	355
	1.5	125	160	200	250	315
	2	140	180	224	280	355
	3	170	212	265	335	425

Example: it is necessary to define the limit diameters of a screw and a nut for the thread junction M12×1.5 -7F8F/6g8g and draw a scheme of tolerance zones.

1. **Internal thread**: M12×1.5 -7F8F.

1.1. The basic major diameter D = d = 12 mm, pitch P = 1.5 mm.

1.2. We define the basic pitch diameter D_2 = D - 1 + 0.026 = 11.026 mm. (table 3.)

1.3. We define the basic minor diameter D_1 = D - 2 + 0.376 = 10.376 mm. (table 3.)

1.4. We define the fundamental deviation FD of the pitch diameter which is equal to the lower deviation EI in this case: $FD_{D2} = EI_{D2}$ = +45 μm = +0.045 mm. (See table 4: letter F, pitch P = 1.5 mm.)

1.5. We draw the basic profile of the thread and the basic diameters D, D_2, D_1. (fig. 5.)

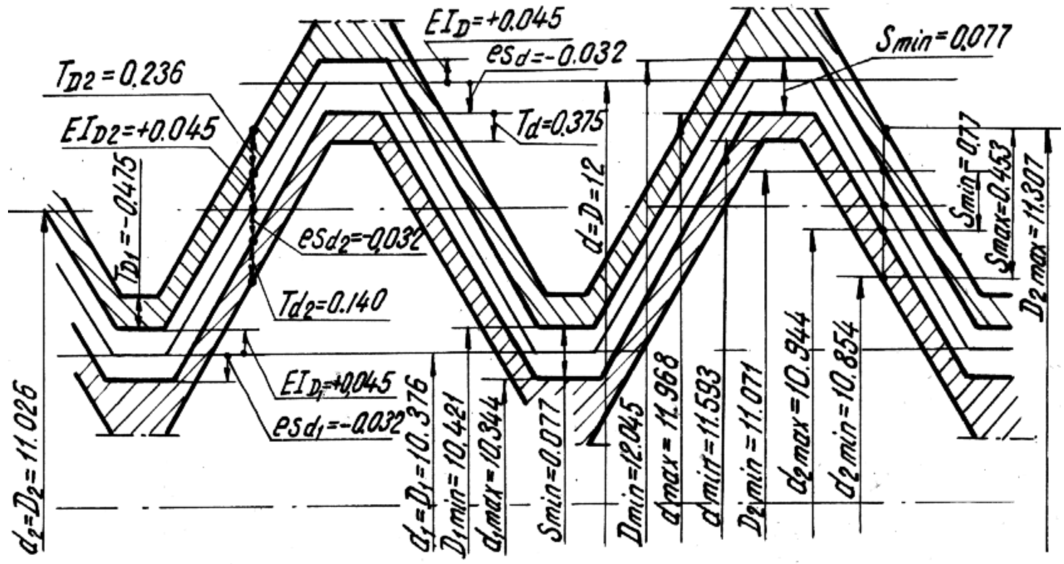


Fig. 5. A scheme of tolerance zones of the external and the internal threads for the thread fit M12×1.5 -7F8F/6g8g.

1.6. We lay the lower deviation of the pitch diameter $EI_{D2}/2$ from the point of intersection of the pitch diameter line D_2 with the basic thread side, fig. 5. We draw a line parallel to the basic thread side. This is the **lower** limit of the tolerance zone of the pitch diameter.

1.7. We define the **minimum** limit pitch diameter of the internal thread: $D_{2\,min}$ = $=D_2 + EI_{D2}$ = 11.026 + (+0.045) = 11.071 mm.

1.8. We define the tolerance of the pitch diameter: T_{D2} = 236 μm = 0.236 mm. (See table 7: tolerance grade 7, D = 12 mm, P = 1.5 mm.)

1.9. We lay the tolerance of the pitch diameter $T_{D2}/2$, fig. 5. We draw a line parallel to the basic thread side. This is the **upper** limit of the tolerance zone of the pitch diameter.

1.10. We define the **maximum** limit pitch diameter of the internal thread: D_{2max}= $=D_{2\,min} + T_{D2}$ = 11.071 + 0.236 = 11.307 mm.

1.11. We define the **upper** deviation ES of the pitch diameter of the internal thread: $ES_{D2} = EI_{D2} + T_{D2}$ = +0.045 + 0.236 = +0.281 mm.

1.12. We define the fundamental deviation FD of the minor diameter which is equal to the lower deviation EI in this case: $FD_{D1} = EI_{D1} = +45$ μm = =+0.045mm. (See table 4: letter F, pitch P = 1.5 mm.)

1.13. We lay the lower deviation of the minor diameter $EI_{D1}/2$ from the basic minor diameter line, fig. 5. We draw a line parallel to the axis of the thread. This is the **lower** limit of the tolerance zone of the minor diameter.

1.14. We define the **minimum** limit minor diameter of the internal thread: $D_{1min}=$ $= D_1 + EI_{D1} = 10.376 + (+0.045) = 10.421$ mm.

1.15. We define the tolerance of the minor diameter: $T_{D1} = 475$ μm = 0.475 mm. (See table 5: tolerance grade 8, P = 1.5 mm.)

1.16. We lay the tolerance of the minor diameter $T_{D1}/2$ from the **minimum** limit minor diameter line, fig. 5. We draw a line parallel to the axis of the thread. This is the **upper** limit of the tolerance zone of the minor diameter.

1.17. We define the **maximum** limit minor diameter of the internal thread: $D_{1\,max} = D_{1\,min} + T_{D1} = 10.421 + 0.475 = 10.896$ mm.

1.18. We define the fundamental deviation FD of the major diameter which is equal to the lower deviation EI in this case: $FD_D = EI_D = +45$ μm = =+0.045 mm. (See table 4: letter F, pitch P = 1.5 mm.)

1.19. We lay the lower deviation of the major diameter $EI_D/2$ from the basic major diameter line, fig. 5. We draw a line parallel to the axis of the thread. This is the **lower** limit of the tolerance zone of the major diameter.

1.20. We define the **minimum** limit major diameter of the internal thread: $D_{min} =$ $=D + EI_D = 12 + (+0.045) = 12.045$ mm.

1.21. The **maximum** limit **major** diameter of the **internal** thread **is not specified**.

2. **External thread**: M12×1.5- 6g8g.

2.1. Basic major diameter d = 12 mm, pitch P = 1.5 mm.

2.2. We define the basic pitch diameter $d_2 = D_2 = d - 1 + 0.026 = 11.026$ mm. (See table 3.)

2.3. We define the basic minor diameter $d_1 = D_1 = d - 2 + 0.376 = 10.376$ mm. (See table 3.)

2.4. We define the fundamental deviation fd of the pitch diameter which is equal to the upper deviation es in this case: $fd_{d2} = es_{d2} = -32$ μm = -0.032 mm. (See table 4: letter g, pitch P = 1.5 mm.)

2.5. We draw the basic profile of the thread and basic diameters $d = D$, $d_2=$ $=D_2$, $d_1== D_1$. (See fig. 5.)

2.6. We lay the upper deviation of the pitch diameter $es_{d2}/2$ from the point of intersection the pitch diameter line d_2 with the basic thread side, fig. 5. We draw a line parallel to the basic thread side. This is the **upper** limit of the tolerance zone of the pitch diameter.

2.7. We define the **maximum** limit pitch diameter of the external thread: $d_{2\,max} =$ $=d_2 + es_{d2} = 11.026 + (-0.032) = 10.994$ mm.

2.8. We define the tolerance of the pitch diameter: T_{d2} = 140 μm = 0.140 mm. (See table 6: tolerance grade 6, d = 12 mm, P = 1.5 mm.)

2.9. We lay the tolerance of the pitch diameter $T_{d2}/2$, fig. 5. We draw a line parallel to the basic thread side. This is the **lower** limit of the tolerance zone of the pitch diameter.

2.10. We define the **minimum** limit pitch diameter of the external thread: $d_{2min} = d_{2\,max} - T_{D2}$ = 10.994 - 0.140 = 10.854 mm.

2.11. We define the **lower** deviation of the pitch diameter: $ei_{d2} = es_{d2} - T_{d2}$ = = -0.032 - 0.140 = -0.172 mm.

2.12. We define the fundamental deviation fd of the major diameter which is equal to the upper deviation es in this case: $fd_d = es_d$ = -32 μm = -0.032 mm. (See table 4: letter g, pitch P = 1.5 mm.)

2.13. We lay the upper deviation of the major diameter $es_d/2$ from the basic major diameter line, fig. 5. We draw a line parallel to the axis of the thread. This is the **upper** limit of the tolerance zone of the major diameter.

2.14. We define the **maximum** limit major diameter of the external thread: $d_{max} = d + es_d$ = 12 + (-0.032) = 11.968 mm.

2.15. We define the tolerance of the major diameter: T_d = 375 μm = 0.375 mm. (See table 6: tolerance grade 8, P = 1.5 mm.)

2.16. We lay the tolerance of the major diameter $T_d/2$ from the **maximum** limit major diameter line, fig. 5. We draw a line parallel to the axis of the thread. This is the **lower** limit of the tolerance zone of the major diameter.

2.17. We define the **minimum** limit major diameter of the external thread:

$$d_{min} = d_{max} - T_d = 11.968 - 0.375 = 11.593 \text{ mm}.$$

2.18. We define the fundamental deviation fd of the minor diameter which is equal to the upper deviation es in this case: $fd_{d1} = es_{d1}$ = -32 μm = -0.032 mm. (See table 4: letter g, pitch P = 1.5 mm.)

2.19. We lay the upper deviation of the minor diameter $es_{d1}/2$ from the basic minor diameter line, fig. 5. We draw a line parallel to the axis of the thread. This is the **upper** limit of the tolerance zone of the minor diameter.

2.20. We define the **maximum** limit minor diameter of the external thread:

$$d_{1\,max} = d_1 + es_{d1} = 10.376 + (-0.032) = 10.344 \text{ mm}.$$

2.21. The **minimum** limit **minor** diameter of the **external** thread **is not specified**.

3. **Clearances:**

3.1. On the pitch diameter: maximum clearance $S_{D2\,max} = D_{2\,max} - d_{2\,min}$ = 11.307 - 10.854 = 0.453 mm or $S_{D2\,max} = ES_{D2} - ei_{d2}$ = +0.281 - (-0.172) = 0.453 mm; minimum clearance $S_{D2\,min} = D_{2\,min} - d_{2\,max}$ = 11.071 - 10.994 = 0.077 mm.

3.2. On the major diameter: $S_{D\,max} = D_{max} - d_{min}$ - is not calculated (D_{max} is not specified); $S_{D\,min} = D_{min} - d_{max}$ = 12.045 - 11.968 = 0.077 mm.

3.3. On the minor diameter: $S_{D1\,max} = D_{1\,max} - d_{1\,min}$ - is not calculated ($d_{1\,min}$ is not specified); $S_{D1\,min} = D_{1\,min} - d_{1\,max}$ = 10.421 - 10.344 = 0.077 mm.

2. Screw Thread Measurement

The size and accuracy of screw threads may be measured with thread micrometers fig. 6), controlled by ring thread gages (fig. 7, a), screw thread plug gages (fig. 7, b), roll thread snap gages, thread comparators of various types, optical comparators, and by the three-wire method (fig. 8).

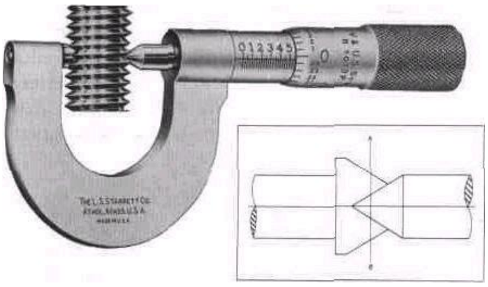
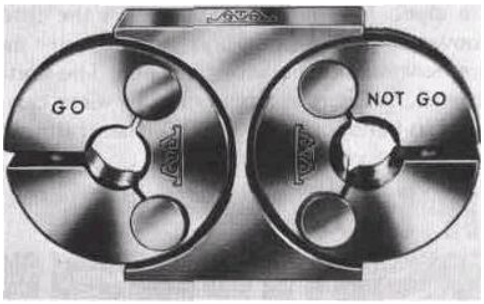
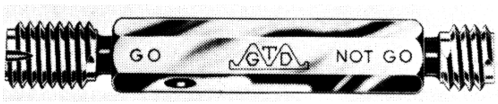


Fig. 6. Thread micrometer.

The emphasis in thread measurement is always on the measurement of the pitch diameter. All methods of measurement of the pitch diameter must provide contact only on the pitch diameter and do not feel errors of the pitch and of the thread angle. That is why the **not-go gage** and the contact points have a cut down profile. The **not-go gage** is designed to check only the pitch diameter. The **go gage** is designed to check the maximum pitch diameter, flank angle, lead, and the clearance at the minor diameter simultaneously. The **go gage** must feel errors of the thread angle and the pitch. That is why the **go gage** has a full profile and a large amount of threads.



a



b

Fig.7. Thread ring (a) and plug (b) gages.

The pitch diameter of 60° V-threads may be measured directly with a **thread micrometer** (fig. 6). The spindle of the micrometer has a 60° conical point, and the anvil has a 60° groove. The anvil point swivels to enable measurement of different pitches.

A given thread micrometer is designed to measure a specific range of screw threads. Care should be taken to select a micrometer with the correct thread range when measuring a specific thread. The micrometer always should be checked for a zero reading before measuring threads. See the inset of fig. 6.

The limits and tolerances on the pitch diameter largely determine the fit of screw threads. Since the **pitch diameter of thread ring gages** and **snap roll gages** is difficult to determine accurately by other methods, these gages are set or fitted with the use of **accurate plug gages**.

Tapped holes are checked for the correct fit with thread limits plug gages. The ***double-end gages*** provide a go gage on one end and a not-go gage on the opposite end, fig. 7, b. The go gage is always the longer of the two, and it has a chip groove for cleaning the threads in the tapped hole being measured.

The accuracy of an **external thread** may be checked with a pair of **thread ring gages**. The pair includes a go gage and a not-go gage, fig. 7, a. The **go gage** is designed to check the maximum pitch diameter, flank angle, lead, and the clearance at the minor diameter simultaneously. The **not-go gage** is designed to check only the pitch diameter to determine whether it is below minimum limits.

To check a thread, both gages are used. If the go gage does not turn on freely, one of the thread elements is not accurate, and the thread will not assemble with the mating part. If the not-go gage turns on the thread, the pitch diameter of the thread is under the specified minimum limits, and the thread will not fit properly with its mating part.

A **three-wire method** (fig. 8) is a method of measuring the pitch diameter of external threads. The three-wire method requires the use of an ordinary outside micrometer and three accurately sized wires. A different **best wire size** is recommended for each pitch and diameter combination. The best wire size is determined by calculation or by selection from a chart of recommended wire sizes. The best wire size is:

$$d_{wb}=0.5P/(\cos\alpha/2), \quad (1)$$

where: P – is the pitch of the thread; α - is the thread angle.

MICROMETER SPINDLE

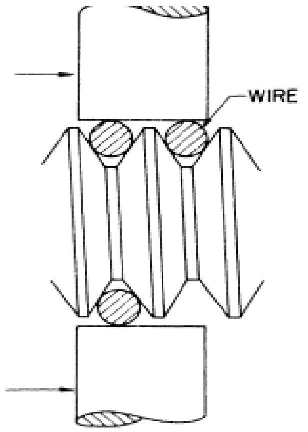


Fig.8.Three-wire thread measurement.

The wires are placed in the thread grooves as in fig. 8, and a micrometer measurement across the wires is made. The correct dimensions for measurement over wires can be found in handbooks for machinists, or the pitch diameter can be calculated:

$$d_2 = M - 3d_w + 0.866P, \quad (2)$$

where M - is the measured size; d_w - is the diameter of the wire; P - is the pitch.

Because the three-wire method is more cumbersome and time consuming to use, many machinists prefer to check the pitch diameter of external threads with a ring gage, thread micrometer, or other instrument. However, the three-wire method is considered to be more accurate than the use of many gages designed for this purpose.

Numerous special thread gaging and measuring devices are available for use in measuring thread elements. Some of these devices measure only one element, such as the pitch diameter. Others measure several thread elements simultaneously.

An **external thread comparator** is used to inspect external threads by means of a single visual reading between indicator tolerance hands. The comparator checks for errors in lead, thread angle, and pitch diameter. The reading on the indicator dial shows whether the cumulative error of all these elements, combined, falls between the high and low limits for a class-of-thread tolerance. The comparator is set to a given size with the use of a master plug thread gage, and the tolerance hands are set for the desired class of thread. An internal thread comparator works on the same principle as the external comparator.

Toolmaker’s microscope (fig. 9, 12) is used for measurements of all parameters of the thread. The toolmaker's microscope is designed especially for use in toolmaking. Images can be enlarged from 10 to 200 times, depending on equipment and job requirements. Images are not reversed as in ordinary microscopes. The platform, called a **stage,** on which workpieces are mounted for measurement, can be moved both crossways and sideways with vernier micrometer accuracy. **A vernier protractor** built into the microscope head, reads to **one minute** (or only 5 minutes sometimes) of arc through the magnifying lens. The microscope optics provide 90° **cross hairs** (fig. 10) and concentric circles with diameters from 0.25-5 mm by 0.25 mm (they are not shown in the fig. 10). An attachment allows cylindrical workpieces to be supported between centers. Direct angular measurement, thread dimensions, radius, hole roundness, and even squareness can be easily checked with a high degree of accuracy.

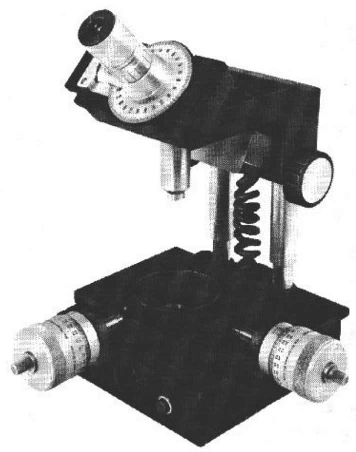


Fig. 9. Toolmaker's microscope.

To measure the thread with the toolmaker's microscope it is necessary to do the following:

1. Angular microscope head *59* (fig. 12) for measurements of angles is set in position of 0° 0' (fig. 11) looking in the **angular head ocular** *11* and revolving its fly-wheel *41* (fig. 12). **One of the cross hairs** (fig. 10) of main ocular *61* (fig. 12) will be **horizontal**.

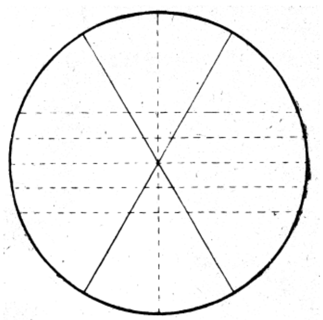


Fig. 10. Cross and inclined hairs.

2. We mount the screw thread between centers *90* on the stage *86* (fig. 12) and touch the horizontal hair with the major diameter of the controlled thread, revolving crossways and sideways fly-wheels *52* and *51* and fly-wheel of rotation stage *86* of the toolmaker’s microscope and **looking in the main ocular** main ocular *61.* We write down the reading of the cross fly-wheel (***a***).
3. Then we revolve cross fly-wheel *52* and **looking in the main ocular** set on the opposite side of the thread major diameter against the horizontal hair, write down the reading of the cross fly-wheel (***b***).

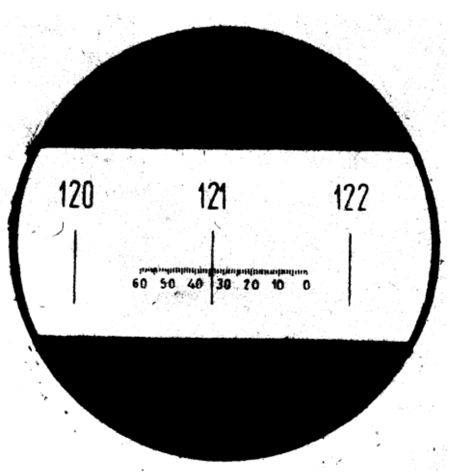


Fig. 11. Reading of 121° 34' of the angular head ocular.

4. We calculate the **real (actual) major diameter** $d = |a - b|$, mm. We write down the first measurement of the major diameter d (d_{r1}) in table 8, column d_r (real).

5. In the same way we repeat measurement of the major diameter d (***d_{r2}***) and calculate the arithmetic average ***$d_{ra} = (d_{r1} + d_{r2})/2$*** and write down it in the stroke "***average value***".
6. We measure the **minor diameter** d_1 2 times (we will touch the horizontal hair with the minor diameter of the controlled thread), calculate and write down these measurements of the minor diameter d_1 (***d_{1r1}*** and ***d_{1r2}***) in table 8, column ***d_{1r}***, and calculate the arithmetic average ***$d_{1ra} = (d_{1r1} + d_{1r2})/2$*** and write it down in the stroke "***average value***".
7. We measure the **pitch diameter** d_2. We touch the inclined hair (the angle is equal to 30º) to the **left side** of the thread profile and write down the reading of the cross fly-wheel (***a***). Then we revolve the cross fly-wheel and set the opposite **right side** of the thread against the inclined hair, write down the reading of the cross fly-wheel (***b***). Here we use the property of parallel lines - the distance between parallel lines is always constant (we measure it perpendicular to the thread axis and that is why there is no need to adjust the **horizontal hair** on the pitch diameter). We calculate the **real pitch diameter** ***$d_2 = |a - b|$***, mm. We write down the first measurement of the pitch diameter d_2 (***d_{2r1}***) in table 8, column ***d_{2r}*.**
8. We measure the **pitch diameter** d_2 2 times, calculate and write down these measurements of the pitch diameter d_2 (***d_{2r1}*** and ***d_{2r2}***) in table 8, column ***d_{2r}***, and calculate the arithmetic average ***$d_{2ra} = (d_{2r1} + d_{2r2})/2$*** and write down it in the stroke "***average value***".
9. We measure the halves of the thread angle α/2 with the help of the head fly-wheel and looking in the main ocular: we touch the vertical hair (the angle is equal to 0º) to the **left side** of the thread profile and write down the **reading of the angular head ocular** (for example, $(\alpha/2)_{r1}$ = 29º 32') in table 8, column $(\alpha/2)_r$.
10. We calculate the **error of the halves of the thread angle**:

$$\Delta(\alpha/2)_{left} = (\alpha/2)_{r1} - (\alpha/2)_{base} ,$$

    and write down this value in table 8, column $\Delta(\alpha/2)_r$. For our example $\Delta(\alpha/2)_{left}$ = 29º 32' - 30º = -28'.
11. We return the head fly-wheel in the position 0º 0' looking in the angular head ocular and revolving its fly-wheel. Then we touch the vertical hair to the **right side** of the thread profile, calculate the real halves of the thread angle $(\alpha/2)_{r2}$ (for example, $(\alpha/2)_{r2}$ = 360º - 228º 43' = 31º 17') and write down the **reading of angular head ocular** (in our example $(\alpha/2)_{r2}$ = 31º 17') in table 8, column $(\alpha/2)_r$.
12. We calculate the error of the halves of the thread angle:

$$\Delta(\alpha/2)_{right} = (\alpha/2)_{r2} - (\alpha/2)_{base} = = 31^o\ 17' - 30^o = +1^o\ 17' = +77',$$

    and write down this value in table 8, column $\Delta(\alpha/2)_r$.

13. We calculate the real arithmetic average ***of the thread angle error***:

$$\Delta(\alpha/2)_{ra} = (|\Delta(\alpha/2)_{left}| + |\Delta(\alpha/2)_{right}|)/2,$$

and write it down in the stroke "***average value***" of table 8.

14. Then we measure the **saved error of the pitch** $\Delta P_{n\ r}$. We return the head fly-wheel in the position 0º 0' looking in the angular head ocular and revolving its fly-wheel. Then we touch the **inclined hair** to the **right side** of the thread profile and write down the reading of the **longitudinal** fly-wheel (***a***).
15. Then we revolve the **side** (longitudinal) fly-wheel and looking in the main ocular we count 4 pitch (we suppose that our screw thread mesh with nut on 4 threads or 4 pitch). We write down the reading of the **side** fly-wheel (***b***).
16. We calculate the **saved real pitch** $P_{n\ r1} = |a - b|$, mm (saved on 4 pitch, i.e. n=4). We write down the first measurement of the pitch $P_{n\ r1}$ in table 8, column $P_{nr\bullet}$.
17. We repeat measurement of the saved real pitch but we will touch the inclined hair to the **left side** of thread profile. We write down the second measurement of the pitch $P_{n\ r2}$ in table 8, column $P_{nr\bullet}$.
18. We calculate the **saved error of pitch** for the first measurement:

$$\Delta P_{n\ r1} = P_{n\ base} - P_{n\ r1} ,$$

and write down this value in table 8, column $\Delta P_{nr\bullet}$. Do it in the same way for the second measurement (calculate $\Delta P_{n\ r2}$).

19. We calculate the real arithmetic average of the saved error of the pitch:

$$\Delta P_{na} = (\Delta P_{n\ r1} + \Delta P_{n\ r2})/2, \text{ mm},$$

and write it down in the stroke "***average value***" of table 8.

20. We calculate **the diametrical compensation of the pitch error** f_p (of saved error of pitch):

$$f_p = 1.732 \cdot \times |\Delta P_{na}| ,$$

where ΔP_{na} is the real arithmetic average of the saved error of the pitch, mm. We write it down in the stroke "***the diametrical compensation of the pitch error*** f_p" of table 8.

21. We calculate **the diametrical compensation of the profile angle** f_α (of the halves of the thread angle):

$$f_\alpha = 0.36 \times P_{base} \times \Delta(\alpha/2)_{ra}, \text{ mkm},$$

where $\Delta(\alpha/2)_{ra}$ is the real arithmetic average of the thread angle error in **angle minutes** ('); P_{base} is the base pitch, **mm**. We transform f_α from mkm to mm and write it down in the stroke "***the diametrical compensation of the profile angle*** f_α" of table 8.

22. We calculate **the resulting pitch diameter** $d_{2\ res}$ **:**

$$d_{2\ res} = d_{2a} + f_p + f_\alpha, \text{ mm.}$$

We write it in the stroke "***the resulting pitch diameter*** $d_{2\ res}$" of table 8.

23. We determine the **usefulness (validity)** of the controlled screw thread, comparing real diameters with **limit diameters**:
    1. We determine the validity of the **major diameter** d_r:

       $$d_{max} \geq d_r \geq d_{min}.$$
    2. We determine the validity of the **minor diameter** d_{1r}:

       $$d_{1r} \leq d_{max}.$$
    3. We determine the validity of the **pitch diameter** d_{2r}:
       a) $d_{2r} \geq d_{2min}$;
       b) $d_{2\ res} \leq d_{2max}$.

Note: we compare d_{2max} with the **resulting pitch diameter** $d_{2\ res}$.

    4. We write down our conclusion (for all diameters and **how to correct the manufacturing errors**) in table 8.

Order of performing work

1. Write down designation of a screw thread.
2. Draw a scheme of tolerance zones and define the limit diameters of the screw thread.
3. Measure **major** (d), **minor** (d_1) and **pitch** (d_2) diameters 2 times and write down their values in table 8**.**

Table 8. Measurements of screw thread parameters with toolmaker's microscope

№ of meas.	Real diameters, mm			Real halve of thread angle, $(\alpha/2)_r$, angle degrees and minutes	Real saved pitch P_n, mm (on n pitch)	Error of halve of thread angle, $\Delta(\alpha/2)_r$, angle min.	Error of saved pitch ΔP_n, mm
	Major, d_r	Minor, d_{1r}	Pitch, d_{2r}				
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1							
2							
average value							
the diametrical compensation of the pitch error $f_p = 1.732 \cdot \times \lvert \Delta P_{na} \rvert =$……………………..mm							
the diametrical compensation of the profile angle $f_\alpha = 0.36 \times P_{base} \times \Delta(\alpha/2)_{ra}$, mkm = mm							
the resulting pitch diameter $d_{2\ res} = d_{2a} + f_p + f_\alpha =$ mm.							

Continuation of Table 8

Conclusion:
Major diameter d:
Minor diameter d_1:
Pitch diameter d_2:
How to correct the manufacturing errors: 1. ***First of all*** it is necessary to … 2. 3. 4.

4. Measure the **thread angle error** $\Delta(\alpha/2)_r$ 2 times and write down its values in table 8**.**
5. Measure the **saved error of pitch** ΔP_n for 4 pitch (n = 4) 2 times and write down its values in table 8**.**
6. Calculate the **diametrical compensation of the pitch error** f_p and write down its value in table 8**.**
7. Calculate the **diametrical compensation of the profile angle** f_α and write down its value in table 8**.**
8. Calculate the **resulting pitch diameter** $d_{2\ res}$ and write down its value in table 8.
9. Determine the **validity** of the controlled screw thread in all diameters.

9.1. We determine the validity of the **major diameter** d_r:

$d_{max} \geq \mathbf{d_r} \geq d_{min}$.

9.2. We determine the validity of the **minor diameter** d_{1r}:

$\mathbf{d_{1r}} \leq d_{max}$.

9.3. We determine the validity of the **pitch diameter** d_{2r}:

a) $d_{2r} \geq d_{2min}$;

b) $d_{2\ res} \leq d_{2max}$.

Note: we compare d_{2max} with **the resulting pitch diameter** $d_{2\ res}$.

10. Write down a conclusion (for all diameters and **how to correct the manufacturing errors**) in table 8.

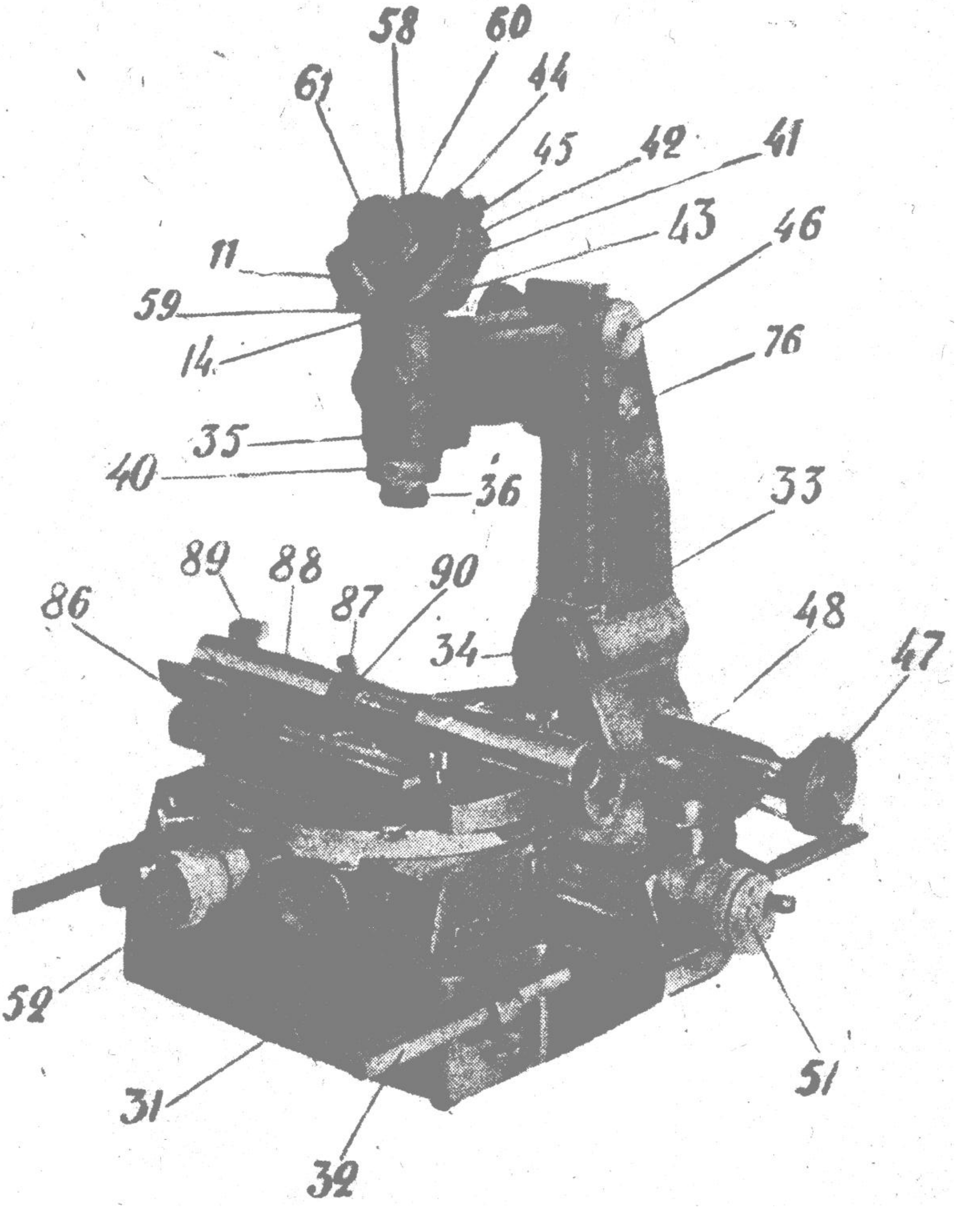


Fig. 12. Big toolmaker’s microscope.

Laboratory work №7
"Inspection of gears"

The purpose of work:

1. To get acquainted with the equipment and methods of gear inspection.
2. To study the basic operations of gear inspection.
3. To estimate the accuracy of the controlled gear of all accuracy norms and write down the accordance designations.

The equipment:

1 Intercenter measurement gauge.
2. Normal measurement gauge.
3. Palpation measurement gauge.
4. Gear-tooth vernier caliper.
5. Gauge for measurement of the saved error of a pitch.
6. Tangent tooth gauge.

Basic rules on the theme of work

1. Introduction. Types of gears and gear nomenclature

A gear is a wheel into which teeth have been cut, see fig. 1. Although friction wheels will transmit motion and power, they are inefficient because slippage occurs even under heavy loads.

Gears may be used to transmit motion between shafts that are parallel, intersecting, or neither parallel nor intersecting. The gear connected to the source of power is called the **driver**, and the one to which motion is transmitted is called the **driven**. When two gears of unequal size are mated, the smaller one is called a **pinion**. A **gear rack** (fig. 1) is a gear that has teeth spaced along a straight line. This permits rotary motion to be changed to straight-line motion, or vice versa. A **basic rack** is one that is the basis for a system of interchangeable gears, see fig. 2.

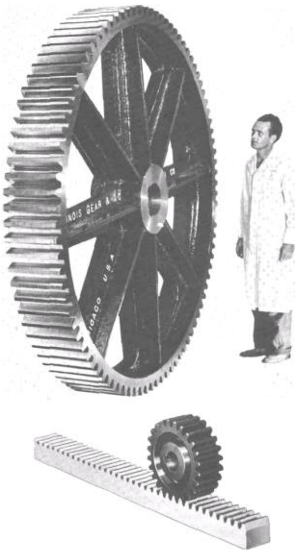


Fig. 1. A large spur gear above and a rack and pinion below.

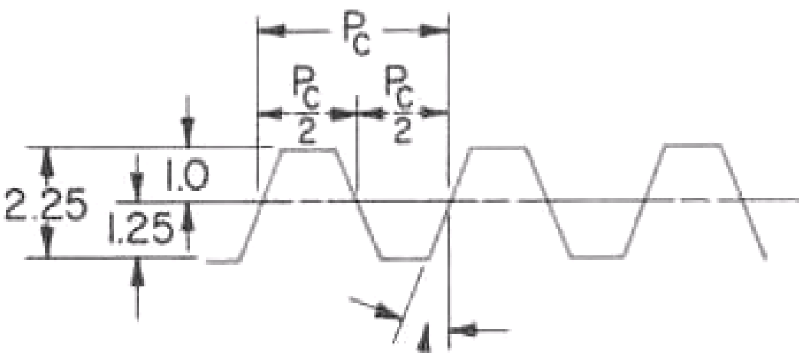


Fig. 2. The SI metric 20° gear tooth form (whole depth is done for 1 mm module).

The most common types of gears are **spur, bevel** and **miter, internal, helical,** and **worm gears**. Modern gears generally have **involute teeth**. This means that the shape of the tooth is generated or drawn with an involute curve. Such a curve may be drawn with a pencil inserted in the loop of a string wound about a cylinder and held taut as the string is unwound. The size of a gear is given in terms of its diameter at the pitch circle, which is called the **pitch diameter d**, fig. 3 (continue to refer to this figure throughout these definitions).

Metric gears are always made according to the **module** (**m**) system, with measurements in millimeters. The **module** (**m**) represents the amount of pitch diameter per gear tooth, and also corresponds to the addendum. Therefore, the higher the module number, the larger the size of the gear tooth. To say that a metric gear has a module of 2 means that it has 2 mm of pitch diameter for each gear tooth. Thus, a 2m, 40-tooth gear would have a pitch diameter of 80 mm ($d = m \cdot z = 2 \cdot 40 = 80$ mm).

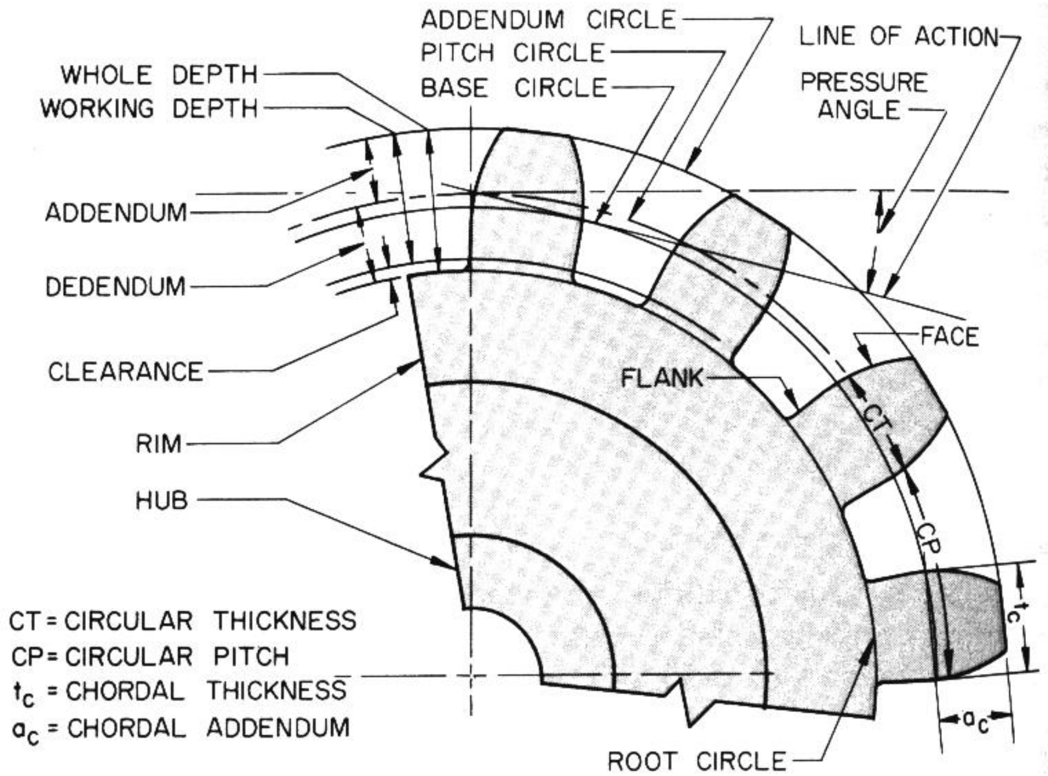


Fig. 3. Gear nomenclature.

The term **circular pitch** (p) refers to the distance along the pitch circle on a gear or along the pitch line on a rack, from a point on one tooth to a corresponding point on the next tooth. Circular pitch corresponds to linear pitch on a gear rack.

Diametral pitch (**P**), **pitch diameter** (**d**), **amount of teeth** (**z**), and **module** (**m**) are all related as shown to the right: $\mathbf{P = m \cdot \pi}$; $\mathbf{d = m \cdot z}$.

The **base circle** is the circle from which involute tooth profiles are derived.

A **pitch circle** is the curve of intersection of a pitch surface of revolution and a plane of rotation. According to theory, it is the imaginary circle that rolls without slipping with a pitch circle of a mating gear.

A **pitch line** corresponds in the cross section of a rack to the pitch circle in the cross section of a gear.

The **addendum circle** coincides with the tops of the teeth in a cross section.

The **root circle** is tangent to the bottoms of the tooth spaces in a cross section.

The **line of action** is the path of contact in involute gears. It is a straight line passing through the pitch point and tangent to the base circles.

Pressure angle (α) is the angle between a tooth profile and the line normal to a pitch surface, usually at the pitch point of the profile. This definition is applicable to every type of gear. The term **pressure angle** originally meant an angle between the line of pressure and the pitch circle. In involute teeth, the pressure angle is often described as the angle between the line of action and the line tangent to the pitch circles.

Center distance (C) is the distance between the parallel axes of spur gears and parallel helical gears or between the crossed axes of crossed helical gears and worm gears. Also, it is the distance between the centers of pitch circles.

Addendum (a) is the height by which a tooth projects beyond the pitch circle or pitch line; also, it is the radial distance between the pitch circle and the addendum circle.

Dedendum (b) is the depth of a tooth space below the pitch circle or pitch line; also, it is the radial distance between the pitch circle and the root circle.

Clearance (c) is the amount by which the dedendum in a given gear exceeds the addendum of its mating gear.

Working depth (h_k) is the depth of engagement of two gears, that is, the sum of their addendums.

Whole depth (h_t) is the total depth of a tooth space, equal to addendum plus dedendum, also equal to working depth plus clearance.

Pitch diameter (D, d) is the diameter of the pitch circle.

Outside diameter (D_O, d_O) is the diameter of the addendum (outside) circle. In a bevel gear, it is the diameter of the crown circle. In a throated worm gear, it is the maximum diameter of the blank. The term applies to external gears.

Root diameter (D_R, d_R) is the diameter of the root circle.

Circular thickness (t_G, t_P) is the length of arc between the two sides of a gear tooth, on the pitch circle unless otherwise specified.

Chordal thickness (t_C) is the length of the chord subtending a circular-thickness arc.

Chordal addendum (a_C) is the height from the top of the tooth to the chord subtending the circular-thickness arc.

Number of teeth or **threads** (**z** or **N**) is the number of teeth contained in the whole circumference of the pitch circle.

Gear ratio (m_G) is the ratio of the larger to the smaller number of teeth in a pair of gears.

Full-depth teeth are those in which the working depth equals ***2 m***.

Stub teeth are those in which the working depth is less than ***2 m***.

2. Fixing of accuracy

12 degrees of accuracy of gears are established for gears and transfers designated in the decreasing order of accuracy: 1, 2..., 12. The norms of admitted deviations of parameters are established for each degree of accuracy. They determine **3 norms of accuracy** and **1 kind of gear interfaces:**

1) kinematics accuracy of gears and transfers;
2) smoothness of work;
3) contacts teeth of gears of transfer;
4) kinds of gears interfaces of transfer.

The degree of accuracy on each norm of accuracy is underlined in a conditional designation of gears strictly under the order. The last two letters specify a kind of interface, whose accuracy is not designated in figures, and letters. Each norm of accuracy does not depend on the others, and they can have various degrees of accuracy, for example, 7-8-7-Bc. Each norm of accuracy can be controlled by several methods and devices, whose choice depends on the degree of accuracy and the purpose of transfer.

2.1. The **kinematics error of transfer** is the difference between the actual and nominal angles of turn of a driven gear of transfer. It is expressed in linear sizes of length of an arch of its pitch circle, $F_{k.e.t.}=(\varphi_2 - \varphi_3)\cdot r$, where r is the radius of the pitch circle of a driven gear; $\varphi_3=\varphi_3 \cdot z_1/z_2$; φ_1 is the actual angle of turn of a driver gear; z_1 and z_2 are the teeth numbers of driver 1 and driven 2 gears. Greatest kinematics error of transfer F'_{ior} is the greatest algebraic difference of values of transfer kinematics error **for a complete cycle** of change of a relative situation of gears.

The complete cycle occurs within the limits of a number of revolutions of the large gear and equals the quotient from division of the teeth number of a smaller gear by the greatest common divisor of the teeth numbers of both transfer gears,

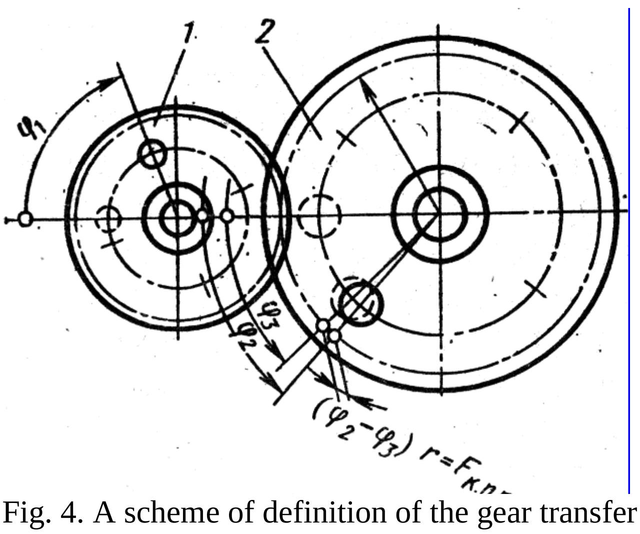


Fig. 4. A scheme of definition of the gear transfer kinematic error.

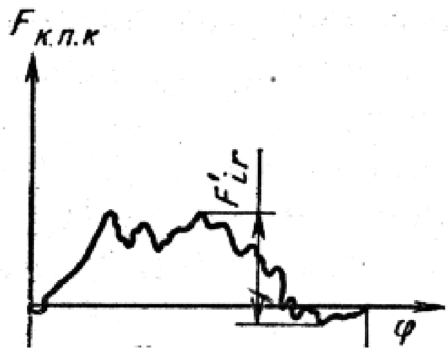


Fig. 5. A definition of the greatest gear wheel kinematic error F'_{ir}.

i.e. on the angle $\varphi_2=2\pi z_1/x$. For example, for $z_1=20$ and $z_2=40$ the greatest common divisor is $x=30$ and $\varphi_2=2\pi 30\backslash 30=2\pi$.

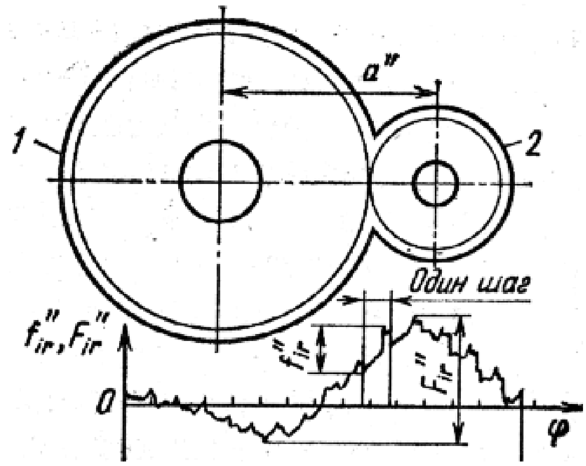
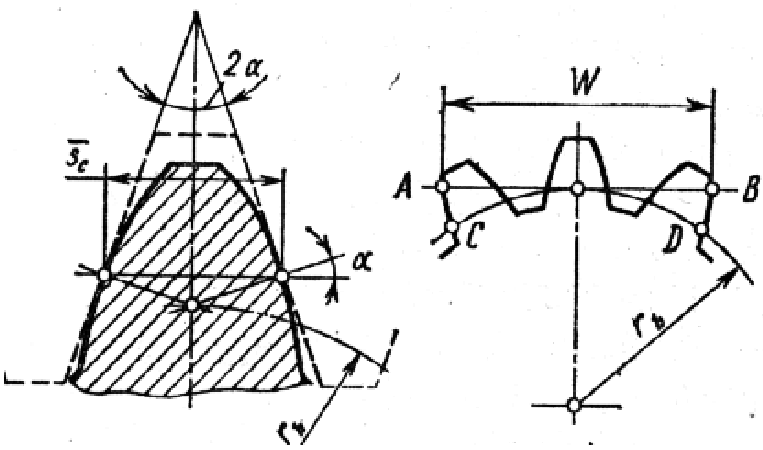


Fig. 6. A definition of fluctuation distance measuring between axes for one revolution of a gear F''_{ir} and its local kinematics errors f''_{ir}. (teeth frequency).

The greatest kinematics error of transfer is limited by the tolerance F'_{io}. This tolerance is equal to the sum of the kinematics error tolerances of its gears, $F'_{io} = F'_{i1} + F'_{i2}$.

The **kinematics error of a gear** is determined from one revolution of a gear. The kinematics error of a gear, made on machine tools using the method of round, occurs because of the discrepancy of the center of the basic circle of gears to the working axis of its rotation, the error of round circuits of the machine tool, discrepancy of the tool and its installation, etc. The kinematics accuracy of gears depends on the errors, their total influence is found once from one revolution of a gear. It is a round error, saved error of the pitch F_{Pkr}, radial palpation of the gear rim F_{rr}, fluctuation of the common normal length F_{vWr} (fig. 7, b) and of the distance measured between the axes for one revolution of a gear F''_{ir} (fig. 6). These errors are measured by devices having corresponding names. One of the errors is supervised usually, the others will correspond approximately to the same degree of accuracy. The choice of the kind of checked error depends on the required degree of kinematics accuracy, the kind of mechanism and presence of the appropriate device. Usually the radial palpation of the gear ring F_{rr} or fluctuation of the distance measured between the axes for one revolution of the gear F''_{ir} is supervised because of the simplicity of control.



a b

Fig. 7. A definition of parameters: constant hord S_c and common normal length W.

2.2. The **smoothness of work** of transfer is determined with the parameters, whose errors are cyclically shown for a revolution of a gear and also make part of the kinematics error. Analytically the kinematics error can be represented as a spectrum of harmonic components, whose amplitude and frequency depend on the character of the errors made. For example, the deviation of a pitch of gearing causes fluctuation of the kinematics error with **teeth frequency** equal to the frequency of entrance of the gear teeth. The cyclic character of errors and possibilities of harmonic analysis enable us to determine these errors by the spectrum of the kinematics error.

Local kinematics errors of the transfer f'_{ior} and gear f'_{ir} are the greatest difference between the local next limit data of the kinematics error of transfer or gear for a complete cycle of rotation of transfer gears. Usually ***fluctuation of the distance measured between the axes on one teeth of a gear*** f''_{ir} is supervised because of the simplicity of control (fig. 6).

The deviation of a pitch f_{ptr} is the kinematics error of a gear at its turn on one nominal angular pitch. The error of the tooth profile f_{fr} is supervised for accurate gears.

2.3. The **contact of transfer teeth** should be as close asr possible. When the contact on lateral surfaces is incomplete, the bearing area decreases, the contact loadings are increased and are allocated non-uniformly, which results in an intensive wear and the teeth may break easily.

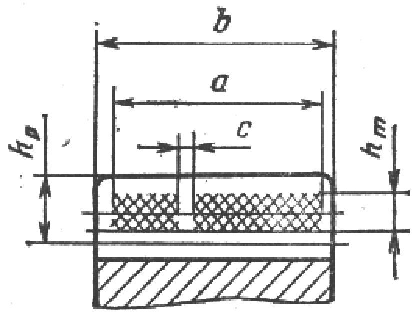


Fig. 8. Definition of the total contact stain.

Usually, the total stain of contact (fig. 8) is supervised on the traces of paint in the assembled transfer after rotation under loading. The stain of contact is defined by relative sizes (percent):

1) **on the length of a tooth** by the ratio of the distance ***a*** between the extreme points of the traces adjoin with a subtraction of the breaks ***c***, exceeding the module ***m*** in mm, to the length of the tooth ***b***, i.e.:

$S_{lr} = [(a-c)/b]\ 100\%$;

2) ***on the height of a tooth*** - by the ratio average (on the length of a tooth) height of the traces adjoin h_m to the height of the active lateral surfaces tooth h_p, i.e.:

$$S_{hr} = (h_m / h_p)\cdot 100\% .$$

Also, the gear standard have the **total error of the contact line** F_{kr}, the **error of the direction of the tooth** $F_{\beta r}$, the **deviation from parallelism of the axes** f_{xy}, the **skew of the axes** f_{yr}, the **accuracy of installation of transfer** which is determined by the deviations between the axes distance f_{ar} (for this error the limiting deviations are established: upper $+f_a$ and lower $-f_a$.)

When the total stain of contact corresponds to the requirements of the standard, the control of other parameters of the gear contact is not required. It is supposed to determine the stain of contact with the help of a measuring (etalon) gear.

2.4. Kinds of interfaces of gear teeth in transfer (kind of lateral clearance). The gear transfers should have a lateral clearance j_n (between non-working teeth profiles of the mating gears) for elimination of possible jamming at heating, maintenance of conditions of greasing course, compensation of errors of manufacturing, assembly and restriction of a dead course at reverse (fig. 9). Such transfer is one-profile (contact only on one working profile). Lateral clearance is determined in section, perpendicular to the tooth direction, in a plane, tangent to the basic cylinders.

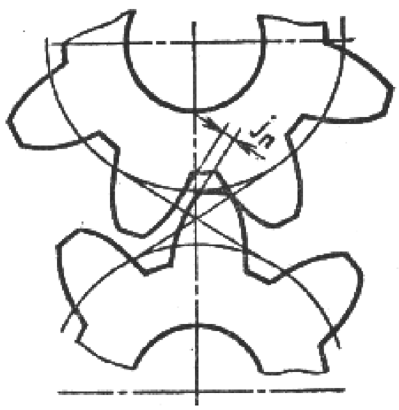


Fig. 9. A lateral clearance j_n .

The system of tolerances on gear transfers establishes a **guaranteed lateral clearance** j_{nmin} , which is the least ordered lateral clearance independent of the degree of accuracy. For example, the most exact transfers of high-speed reducers of turbines are made with large lateral clearances for compensation of temperature deformations. **Six kinds of interfaces** determining various values for j_{nmin} , are established with reduction of a guaranteed clearance: ***A, B, C, D, E, H***. These interfaces apply accordingly to the degrees of accuracy on norms of smoothness of work: 3-12, 3-11, 3-9, 3-8, 3-7, 3-7. For the interface H $j_{n\ min}$=0. The interface of the B kind guarantees the minimal lateral clearance, which prevents jamming of steel transfer from heating at a difference of temperatures of gears and the body equal to 25 ^oC.

The **tolerance** is established for a lateral clearance determined by the difference between the greatest and least clearances. Eight kinds of the tolerances T_{jn} are established for lateral clearance: ***x, y, z, a, b, c, d, h***. The conformity of the kinds of interfaces and kinds of the tolerances is authorized to be changed, using thus and kinds of the tolerances z, y, x. The lateral clearance $j_{n\ min}$, necessary for compensation of temperature deformations, is defined by the formula

$$j_{n\ min} = V + \alpha_W \cdot(\alpha_1 \cdot\Delta t_1 - \alpha_2 \cdot\Delta t_2)\cdot 2\cdot \sin\alpha, \qquad (1)$$

where: V- is the thickness of the layer of greasing between the gear teeth; α_W – is the interaxial distance; α_1 and α_2 - are the temperature factors of linear expansion of the material of gears and the body; Δt_1 and Δt_2 – is the deviation of temperatures of gears and the body from 20^o C; α- is the angle of the profile of the initial contour.

The lateral clearance ensuring normal conditions of greasing is roughly accepted in the limits from 0.01·mm (for low-speed transfers) up to 0.03·mm (for high-speed transfers).

The lateral clearance is achived by radial displacement of the initial contour of a cutting tool from its basic site in the body of a gear (fig. 10). The basic site of the initial contour is the site of a tool, whose basic thickness of a tooth corresponds to close position of two-profile gearing.

The ***least additional displacement of an initial contour*** is nominated depending on the degree of accuracy on norms of smoothness and the kind of interface and is designated ***-E_{Hs} for gears with external teeth*** and +E_{Hs} for gears with internal teeth (fig. 10). The ***tolerance T_H*** for an additional displacement of the initial contour is established depending on the tolerance on the radial palpation F_r and the kind of interface.

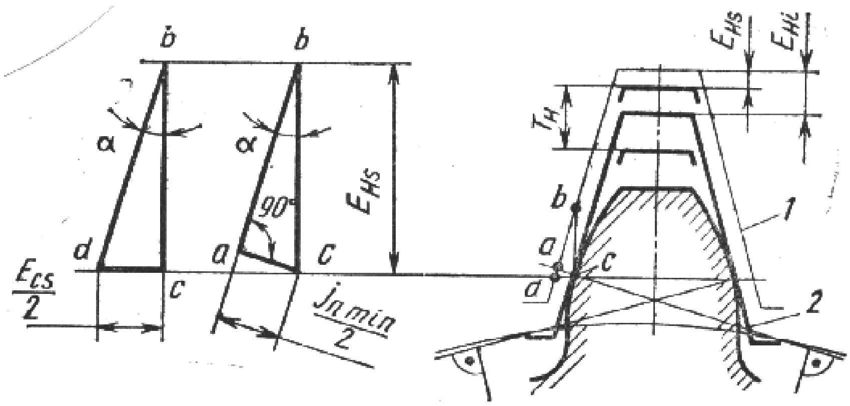


Fig. 10. An initial contour: 1- basic site; 2- actual site.

The least displacement of the initial contour at the clearance K_j , compensating errors of manufacturing, both installation of gears and reduction of lateral clearance is found from

$$E_{Hs} = 0.25\times(j_{n\,min} + K_j)/\sin\alpha. \quad (2)$$

Guaranteed lateral clearance is nominated also by the least deviation of the average length of the common normal -E_{Wms} (+E_{Wmi}) or the least deviation of thickness of a tooth -E_{cs} , or the limiting deviation of measuring interaxial distance $E_{a''s}$ ($E_{a''i}$).

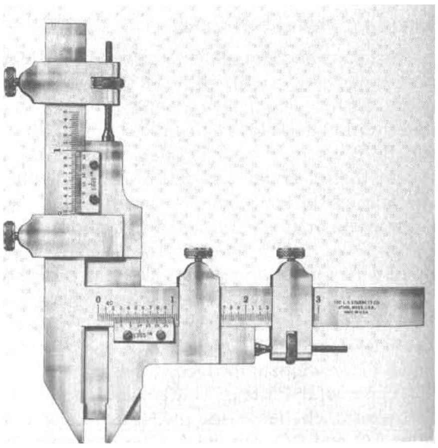


Fig. 11. A gear-tooth vernier caliper.

The tolerances on the average length common normal T_{Wm}, on the thickness of a tooth on the constant chord T_c, and the limiting deviations measuring the interaxial distance are accordingly established as the upper +$E_{a''s}$ and the lower - $E_{a''i}$.

The **chordal thickness** and the **chordal addendum** of spur gear teeth may be accurately checked for size with a gear-tooth vernier caliper, fig. 11. The values for these parts can be found in standard handbooks for machinists. The vertical scale on the vernier caliper is first set at the handbook value for the chordal addendum (sometimes called a corrected addendum). The caliper is then fit onto the tooth, and the chordal thickness is measured using the sliding vernier scale.

3. The complexes of the control

Accuracy of manufacturing gears and transfers are set by the degree of accuracy on the appropriate norms of accuracy, and the requirement to the lateral clearance - by the kind of interface on the norms of the lateral clearance. An example of a designation: 8-B - cylindrical transfer with the degree of accuracy 8 on all three norms, with interface *B* and the tolerance *b* on the lateral clearance.

8-7-6-Bc – the degree of accuracy 8 on the norms of kinematics accuracy, the degree of accuracy 7 on the norms of smoothness of work, the degree of accuracy 6 on the norms of teeth contact, interface *B*, the tolerance on the lateral clearance *c* and conformity between the kind of interface and the class of deviations of interaxial distance.

An example of a designation of transfer with the degree of accuracy *7* on all norms, with the gear interface *C*, with the tolerance on the lateral tolerance *a* and a rougher class of deviations of the interaxial distance *V* and the reduced guaranteed lateral clearance $j_{n\,min}$ =128 microns is: 7-Ca/V -128.

The degree of accuracy of gears and transfers are established depending on the requirements to the kinematics accuracy, smoothness, transmitted capacity and circumferential speed of gears. At a circumferential speed of 10-15 mps the degrees of accuracy 6-7 are applied; at speeds of 20-40 mps – the degrees of accuracy are 4-5. For automobiles the degrees of accuracy 7-6-6-C, 8-7-7-C are applied; for dividing mechanisms - 4-5-5-D, etc.

The control complexes are established for the control of gears. Each norm of accuracy can be controlled with several methods and devices, their choice depending on the degree of accuracy and the purpose of transfer.

The complexes of gear control can be used for this laboratory work:

The first complex:

1) fluctuation of the distance measured between axes for one revolution of a gear $\mathbf{F''_{ir}}$ (fig. 6, 12) is used for estimating the gear accuracy of the **kinematics norm**;

2) fluctuation of the distance measured between the axes on one gear teeth (teeth frequency) $\mathbf{f''_{ir}}$ is used for estimating the **smoothness work norm** (fig. 6);

3) a total stain of contact on the length of the tooth $\mathbf{S_l}$ and on the height of the tooth $\mathbf{S_h}$ (fig.8) is used for estimating of the **teeth contact norm**;

4) the least additional displacement of the initial contour $\mathbf{-E_{Hs}}$ and the tolerance $\mathbf{T_H}$ for an additional displacement of the initial contour is used for estimating the kind of interface of gear teeth in transfer **(**lateral clearance) (fig. 10, 17).

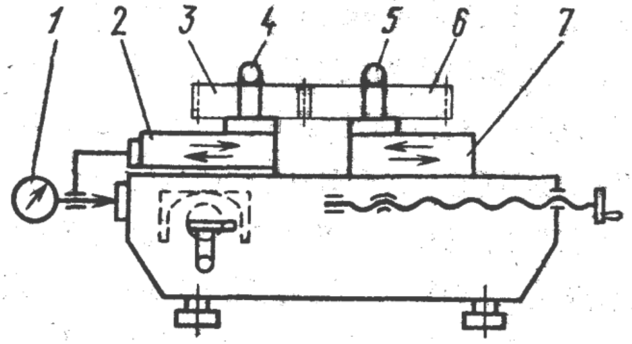


Fig. 12. Intercenter measurement (fluctuation of the distance measured between axes for one revolution of the gear $\mathbf{F''_{ir}}$).

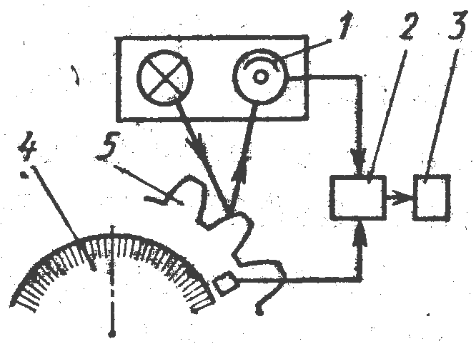


Fig. 13. Measurement of the saved error of the pitch $\mathbf{F_{Pkr}}$.

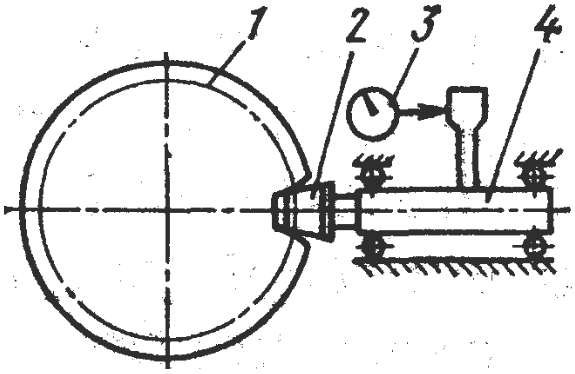


Fig. 14. Measurement of the radial palpation of the gear rim $\mathbf{F_{rr}}$

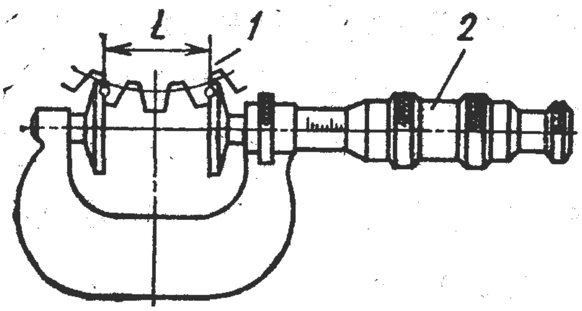


Fig. 15. Measurement of the fluctuation of the common normal length $\mathbf{F_{vWr}}$.

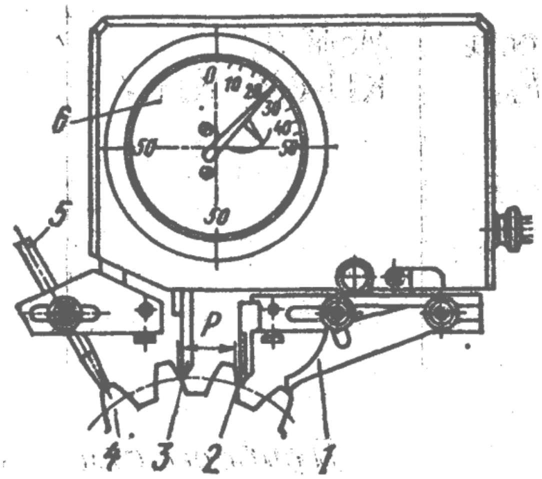


Fig. 16. Measurement of the deviation of the pitch $\mathbf{f_{ptr}}$.

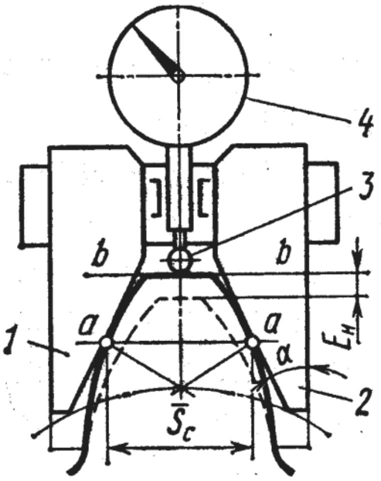


Fig. 17. Measurement of the least additional displacement of the initial contour $\mathbf{-E_{Hs}}$ and the tolerance $\mathbf{T_H}$

The second complex:

1) radial palpation of the gear rim $\mathbf{F_{rr}}$ (fig. 14) is used for estimating the gear accuracy of the **kinematics norm**;
2) the deviation of the pitch $\mathbf{f_{ptr}}$ (fig. 13) is used for estimating of the **smoothness work norm**;
3) a total stain of contact on the length of the tooth $\mathbf{S_l}$ and on the height of the tooth $\mathbf{S_h}$ (Fig.8) is used for estimating the **teeth contact norm**;
4) the least additional displacement of the initial contour $\mathbf{-E_{Hs}}$ and the tolerance $\mathbf{T_H}$ for an additional displacement of the initial contour is used for estimating the **kind of interface of gear teeth in transfer (**lateral clearance) (fig. 10).

For estimating the gear accuracy of the **kinematics norm** we can use the error of the pitch $\mathbf{F_{Pkr}}$, the fluctuation of the common normal length $\mathbf{F_{vWr}}$ (fig. 7, b and 15).

4. Measurements

1. **Measurements of the distance fluctuation between axes for one revolution of the gear** $\mathbf{F''_{ir}}$ (fig. 6, 12) (used for estimating of the **kinematics norm** accuracy**)**:

a) checked gear *6* is mounted on mandrel *5* (fig. 12);
b) then it contacts etalon gear *3* which is mounted on mandrel *4* on moveable springing support *2* until the small pointer of dial indicator *1* is settled against the nearest division of the small indicator face. Clamp the adjustment support *7* (fig. 12);
b) turn the main face of the indicator until its zero division is settled against the big pointer of the dial indicator;
c) match the point of the contact of the gears by a piece of chock;
d) revolve the checked gear *6* for one revolution or for a complete cycle.
Note: we have to revolve gears **only** by the **gear *6***;
e) during the revolution notch only the limit dispositions of the indicator pointer (for example, from +0.12 mm to -0.03 mm);
f) calculate the distance fluctuation measured between the axes for one revolution of the gear $\mathbf{F''_{ir}}$: $\mathbf{F''_{ir}} = +0.12 - (-0.03) = 0.15$ mm;
g) compare $\mathbf{F''_{ir}}$ with the tolerance of the distance fluctuation measured between the axes for one revolution of the gear $\mathbf{F''_{i}}$ (table 1) and define the usefullness of the checked gear or the gear grade of accuracy on the **kinematics norm**.

For example: we measure a gear with the module m =3 mm and z = 24, $d = m \times z = 3 \times 24 = 72$ mm. Measurements of the distance fluctuation between the axes for one revolution of the gear is $\mathbf{F''_{ir}} = 0.15$ mm = 150 mkm.

We find in table 1 the tolerance $\mathbf{F''_{i}}$: in column d = 50…125 mm and stroke m =3 mm for the grade of tolerance 11 $\mathbf{F''_{i}}$ = 140 mkm; for grade of tolerance 12 $\mathbf{F''_{i}}$ = 175 mkm. It means that the accuracy of the gear on the **kinematics norm** is 12 ($\mathbf{F''_{ir}} = 150 < \mathbf{F''_{i}} = 175$**).**

Table 1. Norms of kinematics accuracy (tolerances are used in mkm)

Grade of accuracy	Designation	Module *m*, mm	Pitch diameter, mm ($d = m \cdot z$)				
			<50	**50…125**	**125…280**	**280…560**	**560…1000**
7	F''_i	***1…2***	42	53	67	90	95
		2…3.55	45	56	70	90	100
		3.55…6	48	60	75	95	105
	F_r	***1…2***	30	38	44	55	65
		2…3.55	32	40	47	58	68
		3.55…6	34	42	50	61	71
	F_{Pk}	***1…16***	36	48	55	80	90
	F_{vW}	***1…16***	15	24	36	56	76
8	F''_i	***1…2***	53	67	85	105	120
		2…3.55	56	70	90	110	125
		3.55…6	60	75	95	120	140
	F_r	***1…2***	38	48	60	75	85
		2…3.55	40	50	63	80	90
		3.55…6	42	53	67	85	100
	F_{Pk}	***1…16***	50	67	80	110	125
	F_{vW}	***1…16***	19	30	45	70	100
9	F''_i	***1…2***	67	85	105	130	150
		2…3.55	70	90	110	140	150
		3.55…6	75	95	120	150	170
	F_r	***1…2***	48	60	75	95	110
		2…3.55	50	63	80	100	110
		3.55…6	53	67	85	105	120
	F_{Pk}	***1…16***	65	86	105	140	160
	F_{vW}	***1…16***	25	36	56	90	140
10	F''_i	***1…2***	85	100	120	170	180
		2…3.55	90	105	140	175	200
		3.55…6	95	110	150	180	220
	F_r	***1…2***	60	70	85	120	130
		2…3.55	63	75	100	125	140
		3.55…6	67	80	105	130	160
	F_{Pk}	***1…16***	80	105	140	160	195
	F_{vW}	***1…16***	35	46	76	116	165
11	F''_i	***2…3.55***	105	140	175	200	250
	F_r	***2…3.55***	75	100	125	140	160
	F_{Pk}	***1…16***	105	140	160	195	220
	F_{vW}	***1…16***	46	76	116	165	190
12	F''_i	***2…3.55***	140	175	200	250	300
	F_r	***2…3.55***	100	125	140	160	185
	F_{Pk}	***1…16***	140	160	195	220	245
	F_{vW}	***1…16***	76	116	165	190	215

2. **Measurements of the distance fluctuation between the axes on one gear tooth** (**teeth frequency)** $\mathbf{f''_{ir}}$ (fig. 6, 12) (used for estimating the **smoothness work norm)**:

a) checked gear *6* is mounted on a mandrel *5* (fig. 12);

b) then it contacts etalon gear *3* which is mounted on mandrel *4* on moveable springing support *2* until the small pointer of dial indicator *1* is settled against the nearest division of the small indicator face. Clamp the adjustment support *7* (fig. 12);

b) turn the main face of the indicator until its zero division is settled against the big pointer of the dial indicator;

c) match the point of the of the gears by a piece of chock;

d) revolve the checked gear *6* for one revolution or for a complete cycle.
Note: we have to revolve the gears **only** by **gear *6***;

e) during the revolution notch the readings of the **local fluctuations** of the distance measured between the axes (fig. 6). For example, from 0 mm to +0.02 mm, the value $\mathbf{f''_{ir}}$ is 0.02 mm (readings number 1 in table 2);

Table 2. Example of measurements of teeth frequency $\mathbf{f''_{ir}}$, mm

№	Readings	Value		№	Readings	Value		№	Readings	Value
1	0…+0.02	0.02		10	+0.06…+0.09	0.03		19	+0.080…+0.05	0.03
2	+0.02…+0.03	0.01		11	+0.09…+0.07	0.02		20	+0.05…+0.02	0.03
3	+0.03…-0.01	0.04		12	+0.07…+0.06	0.01		21	+0.02…+0.03	0.01
4	-0.01…-0.03	0.02		**13**	+0.06…+0.11	**0.05**		22	+0.03…+0.05	0.02
5	-0.03…+0.02	0.05		14	+0.11…+0.08	0.02		23	+0.05…+0.02	0.03
6	+0.02…+0.03	0.01		15	+0.08…+0.11	0.03		24	+0.02…0	0.02
7	+0.03…+0.05	0.02		16	+0.11…+0.09	0.02		*25*	*+0.02…+0.03*	*0.01*
8	+0.05…+0.04	0.01		17	+0.09…+0.12	0.03				
9	+0.04…+0.06	0.02		18	+0.12…+0.08	0.04				

f) calculate the fluctuation of the distance measured between the axes on one gear tooth $\mathbf{f''_{ir}}$ – it is the largest value between the largest and smallest readings. For our example (table 2) teeth frequency $\mathbf{f''_{ir}}$ = 0.05 mm= 50 mkm (number 13);

g) compare $\mathbf{f''_{ir}}$ with the tolerance of the distance fluctuation measured between the axes for one revolution of the gear $\mathbf{f''_{i}}$ (table 3) and define the usefullness of the checked gear or the gear grade of accuracy on the **smoothness work norm**.

For example: we measure a gear with the module m =3 mm and z = 24, $d = m\times z = 3\times 24 = 72$ mm. Measurements of the distance fluctuation between the axes on one gear tooth is $\mathbf{f''_{ir}}$ = 50 mkm.

We find in table 3 the tolerance $\mathbf{f''_{i}}$: in column d =***50…125*** mm and stroke m =3 mm for the grade of tolerance 9 $\mathbf{f''_{i}}$ = 40 mkm; for the grade of tolerance 10 $\mathbf{f''_{i}}$ = 50 mkm. It means that the accuracy of the gear on the **smoothness work norm** is 10 ($\mathbf{f''_{ir}} = 50 \leq \mathbf{f''_{i}} = 50$**).**

Table 3. Norms of smoothness work accuracy (tolerances are used in mkm)

Grade of accuracy	Desig-nation	Module m, mm	Pitch diameter, mm ($d = m \cdot z$)				
			<50	**50…125**	**125…280**	**280…560**	**560…1000**
6	f''_i	***1…2***	14	15	16	17	19
		2…3.55	15	16	17	19	20
		3.55…6	17	18	19	20	22
	f_{pt}	***1…2***	±10	±11	±12	±12	±13
		2…3.55	±11	±12	±12	±13	±14
		3.55…6	±12	±13	±13	±14	±15
	f_f	***2…3.55***	8	9	10	12	15
7	f''_i	***1…2***	20	21	22	24	26
		2…3.55	21	22	24	26	28
		3.55…6	24	25	26	28	30
	f_{pt}	***1…2***	±14	±15	±16	±17	±19
		2…3.55	±15	±16	±17	±18	±20
		3.55…6	±17	±18	±19	±20	±22
	f_f	***2…3.55***	11	12	14	17	21
8	f''_i	***1…2***	28	30	32	34	38
		2…3.55	30	32	34	38	40
		3.55…6	34	36	38	40	45
	f_{pt}	***1…2***	±20	±21	±22	±24	±26
		2…3.55	±21	±22	±24	±26	±28
		3.55…6	±24	±25	±26	±28	±30
	f_f	***2…3.55***	15	16	19	24	30
9	f''_i	***1…2***	34	36	40	42	45
		2…3.55	38	40	42	45	50
		3.55…6	42	45	48	50	56
	f_{pt}	***1…2***	±26	±30	±32	±34	±38
		2…3.55	±30	±32	±34	±38	±40
		3.55…6	±34	±36	±38	±40	±45
	f_f	***2…3.55***	21	25	28	32	40
10	f''_i	***1…2***	45	45	50	56	60
		2…3.55	48	50	56	60	63
		3.55…6	53	56	60	63	70
	f_{pt}	***1…2***	±38	±40	±45	±48	±53
		2…3.55	±42	±45	±48	±53	±56
		3.55…6	±45	±50	±53	±56	±60
	f_f	***2…3.55***	30	35	38	42	50
11	f''_i	***2…3.55***	60	63	68	75	78
	f_{pt}	***2…3.55***	±52	±55	±58	±63	±66
	f_f	***2…3.55***	40	45	48	52	60
12	f''_i	***2…3.55***	70	73	78	85	88
	f_{pt}	***2…3.55***	±62	±65	±68	±73	±76
	f_f	***2…3.55***	50	55	58	62	70

3. **Measurements of the total stain of contact** (fig. 8) is supervised on the traces of paint in the assembled transfer after rotation under loading:

a) checked gear *6* is mounted on mandrel *5* (fig. 12);

b) then it contacts the etalon gear *3* which is mounted on mandrel *4* on moveable springing support *2* until the small pointer of dial indicator *1* is settled against the nearest division of the small indicator face. Clamp the adjustment support *7* (fig. 12);

c) paint the lateral surfaces of the gear with a special liquid;

d) revolve the checked gear *6* for several revolutions. **Note**: we have to revolve gears **only** by the **gear *6***;

e) find a tooth with the smallest stain of contact. Measure it on the length and height of the tooth (fig. 8). For example, the stain of contact is defined by relative sizes (percent):

1) on the length of a tooth: $S_{lr}=[(a\text{-}c)/b]\times 100\% =[(10\text{-}4)/20]\times 100\% =30\%$;

2) on the height of a tooth: $S_{hr} = (h_m/ h_p) \times 100\% = (0.3/ 2)\times 100\% = 15\%$;

f) compare S_l and S_h with the tolerance of the stain of contact (table 4) and define the usefullness of the checked gear or the gear grade of accuracy on the **contact of transfer teeth norm**.

For example: we measure the gear with the module m =3 mm and z = 24, $d = m\times z = 3\times 24 = 72$ mm. Measurements of the stain of contact are S_{lr}=30%, S_{hr}=15%.

We find in table 4 the tolerance $\boldsymbol{S_l}$: in column "*L*<**40** mm" and in stroke "*a stain of contact*". For the grade of tolerance 9 $\boldsymbol{S_l} \geq 30\%$; for the grade of tolerance 10 $\boldsymbol{S_l} \geq 40\%$. We take the grade of tolerance 9 (initially, as S_{lr}=30%).

We find in table 4 the tolerance $\boldsymbol{S_h}$: in column "*L*<**40** mm" and stroke "*a stain of contact*". For the grade of tolerance 10 $\boldsymbol{S_h} \geq 20\%$; for the grade of tolerance 11 $\boldsymbol{S_h} \geq 15\%$. We can take the grade of tolerance 11 (initially, as S_{hr}=15%.).

It means that the gear grade of accuracy on the **contact of transfer teeth norm** is **11** (the worst).

Table 4. Norms of contact of transfer teeth accuracy (tolerances are used in mkm)

Grade of accuracy	Designation	Module ***m***, mm	Length of a contact, mm				
			<40	**40…100**	**100…160**	**160…250**	**250…400**
6	a total stain of contact, %	***1…16***	on the length of a tooth S_l not less than 50 %, on the height of a tooth S_h not less than 70 %				
	$\mathbf{f_x}$	***1…16***	10	12	16	19	24
	$\mathbf{f_y}$	***1…16***	10	12	16	19	24
7	a total stain of contact, %	***1…16***	on the length of a tooth S_l not less than 45 %, on the height of a tooth S_h not less than 60 %				
	$\mathbf{f_x}$	***1…16***	12	16	20	24	28
	$\mathbf{f_y}$	***1…16***	12	16	20	24	28
8	a total stain of contact, %	***1…16***	on the length of a tooth S_l not less than 30 %, on the height of a tooth S_h not less than 40 %				
	$\mathbf{f_x}$	***1…16***	20	25	32	38	45
	$\mathbf{f_y}$	***1…16***	20	25	32	38	45
9	a total stain of contact, %	***1…16***	on the length of a tooth S_l not less than 20 %, on the height of a tooth S_h not less than 25 %				
	$\mathbf{f_x}$	***1…16***	32	40	50	60	75
	$\mathbf{f_y}$	***1…16***	32	40	50	60	75
10	a total stain of contact, %	***1…16***	on the length of a tooth S_l not less than 15 %, on the height of a tooth S_h not less than 20 %				
	$\mathbf{f_x}$	***1…16***	50	63	80	105	120
	$\mathbf{f_y}$	***1…16***	50	63	80	105	120
11	a total stain of contact, %	***1…16***	on the length of a tooth S_l not less than 10 %, on the height of a tooth S_h not less than 15 %				
	$\mathbf{f_x}$	***1…16***	70	73	100	125	140
	$\mathbf{f_y}$	***1…16***	70	73	100	125	140
12	a total stain of contact, %	***1…16***	on the length of a tooth S_l not less than 7 % , on the height of a tooth S_h not less than 12 %				
	$\mathbf{f_x}$	***1…16***	100	110	130	155	170
	$\mathbf{f_y}$	***1…16***	100	110	130	155	170

4. **Measurements of the kinds of interface of gear teeth in transfer (kind of lateral clearance)** (fig. 9):

a) find an etalon shaft with the module *m* corresponding to the module *m* of the checked gear;

b) place the etalon shaft with the module *m* between two parts *1* and *2* of a **tangent tooth gauge** prism (fig. 17), appropriately in the middle of their working sides (*a - a*). Clamp the adjustment support (prisms) *1* and *2*;

c) insert dial indicator *4* until measured rod *3* touches the etalon shaft side and small pointer is settled against the nearest division of the small indicator face. Clamp the dial indicator *4*;
d) turn the main face of the indicator until its zero division is settled against the big pointer of the dial indicator. Write down the adjustment reading (for example, 2.00 mm). **Note:** don't turn the main face of the indicator after that**!**
e) place a checked gear tooth between two parts *1* and *2* of a tangent tooth gauge prism;
f) write down the adjustment reading (for example, 2.29 mm). Continue to measure all the gear teeth (table 5).

Table 5. Example of measurements of lateral clearance kind, mm

№	Readings		№	Readings		№	Readings
1	2.29		10	2.19		19	2.46
2	2.27		11	2.21		20	2.43
3	2.24		12	2.23		21	2.40
4	2.19		13	2.27		22	2.37
5	2.19		14	2.29		23	2.39
6	**2.17**		15	2.34		24	2.34
7	2.19		16	2.38		*25*	*2.29*
8	2.18		17	2.45			
9	2.20		18	**2.48**			

g) find the smallest and largest values. For our example (table 5) they are **2.17** and **2.48**, correspondingly;
h) the difference between the smallest value and the adjustment reading (for our example it is 2.00 mm) is the least additional displacement of the initial contour **-E_{Hsr}** . For our example (table 5) it is **E_{Hsr}**= 2.17–2.00 = 0.17 mm = =170 mkm.

In table 6 we find the tolerance **E_{Hs}** for the kind of interface in column *d* = 50…80 mm (*d* = 72 mm) and in stroke grade of accuracy 10 on the **smoothness work norm**. It corresponds to the kind of interface (the kind of deviation or guaranteed clearance) ***B*** (**E_{Hs}**=180 mkm when measured value **E_{Hsr}**=170 mkm);
i) the difference between the largest and smallest values corresponds to the tolerance **T_{Hr}** for an additional displacement of the initial contour. For our example (table 5) it is **T_{Hr}**= 2.48–2.17 = 0.31 mm = 310 mkm.

In table 7 we find the tolerance **T_H** for the kind of interface in column of radial palpation tolerance of the gear rim **F_r** (for our example the accuracy of the gear on the **kinematics norm** is 12, and we find **F_r** in table 1 for *z*=24, *m*=3 mm, *d*=72 mm. It is F_r=125 mkm). For our example F_r=125 mkm, and the nearest tolerance **T_H** =360 mkm when measured value **T_{Hr}.**=310 mkm. It corresponds to the kind of lateral clearance tolerance ***a***;
j) we can write for the kind of interface of gear teeth in transfer (lateral clearance) *Ba*.

Full designation of gear accuracy **for our example** is *12 -10 -11 - Ba*.

Table 6. The least additional displacement of an initial contour **-E_{Hs} (-$A_{He'}$) , +E_{Hi} (+A_{Hi})**
(kinds of interfaces of gears teeth in transfer)
(m≥1 mm, tolerances of the least additional displacements are used in mkm)

Kind of gear inter-face	Grade of accuracy on ***smooth-ness work norm***	Pitch diameter *d*, mm								
		<12	12-20	20-32	32-50	**50-80**	80-125	125-180	180-250	
H	3 - 6	12	12	12	12	12	14	16	18	
	7	13	13	13	13	13	15	18	20	
E	3 - 6	30	30	30	30	30	35	40	46	
	7	34	34	34	34	34	40	45	50	
D	3 - 6	48	48	48	48	48	55	63	70	
	7	52	52	52	52	52	60	70	80	
	8	55	55	55	55	55	65	75	85	
C	3 - 6	75	75	75	75	75	85	100	115	
	7	80	80	80	80	80	95	110	125	
	8	90	90	90	90	90	105	120	140	
	9	100	100	100	100	100	110	130	150	
B	3 - 6	120	120	120	120	120	140	160	185	
	7	130	130	130	130	130	150	170	200	
	8	140	140	140	140	140	170	190	220	
	9	160	160	160	160	160	180	200	240	
	10	**180**	**180**	**180**	**180**	**180**	**200**	**220**	**260**	
A	3 - 6	190	190	190	190	190	220	250	290	
	7	200	200	200	200	200	240	280	320	
	8	220	220	220	220	220	260	300	340	
	9	250	250	250	250	250	280	320	360	
	10	**260**	**260**	**260**	**260**	**260**	**300**	**340**	**400**	

Table 7. The tolerances of additional displacement of an initial contour $\mathbf{T_H}$
(kind of lateral clearance tolerance)
(m≥1 mm, tolerances of the additional displacements are used in mkm)

Kind of lateral clearance tolerance	Tolerances of gear rim radial palpation $\mathbf{F_r}$, mkm														
	<8	8-10	10-12	12-16	16-20	20-25	25-32	32-40	40-50	50-60	60-80	80-100	**100-125**	125-160	160-200
h	28	30	32	36	40	45	52	60	70	80	95	120	140	170	220
d	34	38	40	45	50	55	65	75	90	100	125	150	180	220	280
c	42	45	50	55	63	70	80	95	110	130	160	200	220	280	360
b	55	60	65	70	80	90	105	120	140	160	200	240	280	360	420
a	70	75	80	90	100	110	130	150	180	200	250	300	360	450	560
z	90	95	100	110	130	140	160	200	220	250	300	360	450	560	680
y	110	120	130	140	160	180	200	240	280	320	360	450	560	680	850
x	140	150	160	180	200	220	250	280	320	360	450	560	680	850	1060

Table 8. The least deviation of thick teeth A_{ce} (A_{ci}) for spur gear
(kinds of interfaces of gears teeth in transfer)
(m≥1 mm, tolerances of the least deviation of thick teeth are used in mkm)

Kind of gear inter-face	Grade of accuracy on ***smooth-ness work norm***	Pitch diameter *d*, mm						
		< 80	80- 125	125-180	180-250	250-315	315-400	400-500
		Deviations $\mathbf{A_{ce}}$ ($\mathbf{A_{ci}}$), mkm						
H	3 - 6	9	10	12	13	15	17	18
	7	10	11	13	14	16	18	20
E	3 - 6	22	25	30	34	38	42	45
	7	25	30	32	36	40	45	50
D	3 - 6	34	40	45	58	60	65	70
	7	38	45	50	60	65	70	80
	8	40	48	55	63	70	80	90
C	3 - 6	55	63	75	85	95	100	110
	7	60	70	80	90	100	110	125
	8	65	75	85	100	120	125	140
	9	70	80	95	110	125	130	150
B	3 - 6	90	100	110	130	150	170	180
	7	95	110	125	150	170	180	200
	8	100	125	140	160	180	200	220
	9	120	130	150	170	200	220	240
	10	130	140	160	190	220	240	260
A	3 - 6	140	160	180	200	220	260	300
	7	150	170	200	240	260	300	320
	8	160	190	220	250	280	320	360
	9	180	200	240	260	300	360	380
	10	190	220	250	300	340	380	450

Table 9. Tolerance of thick teeth deviation $\mathbf{T_c}$ for a spur gear
(kind of lateral clearance tolerance)
(m≥1 mm, tolerances of thick teeth deviation are used in mkm)

Tolerances of gear radial palpation $\mathbf{F_r}$, mkm	Kind of lateral clearance tolerance							
	h	**d**	**c**	**b**	**a**	**z**	**y**	**x**
< 8	21	25	30	40	52	65	80	100
8 – 10	22	28	34	45	55	70	85	110
10 – 12	24	30	36	48	60	75	95	120
12 – 16	26	32	40	52	65	80	100	130
16 – 20	28	36	45	58	75	95	120	150
20 – 25	32	42	52	65	85	110	130	170
25 – 32	38	48	60	75	95	120	150	180
32 – 40	42	55	70	85	110	130	160	200
40 – 50	50	65	80	100	130	150	180	220
50 – 60	60	75	95	120	150	180	220	260
60 – 80	70	90	110	130	180	220	260	320
80 – 100	90	110	140	170	220	260	320	400
100 – 125	110	130	170	200	260	320	400	500
125 – 160	130	160	200	250	320	400	500	630
160 – 200	160	200	260	320	400	500	630	750

Laboratory work №8
"Inspection of surface roughness"

The purpose of work:

1. To make students acquainted with the equipment and methods of surface roughness.
2. To help students acquire elementary skills of experimental research work when carrying out laboratory work.
3. To study the basic operations of surface roughness.
4. To estimate the accuracy of controlled parts and write the correspoding designations.

Equipment and materials:

1 Profilometer-amplifier.
2. Parts.

The basic rules on a theme of work

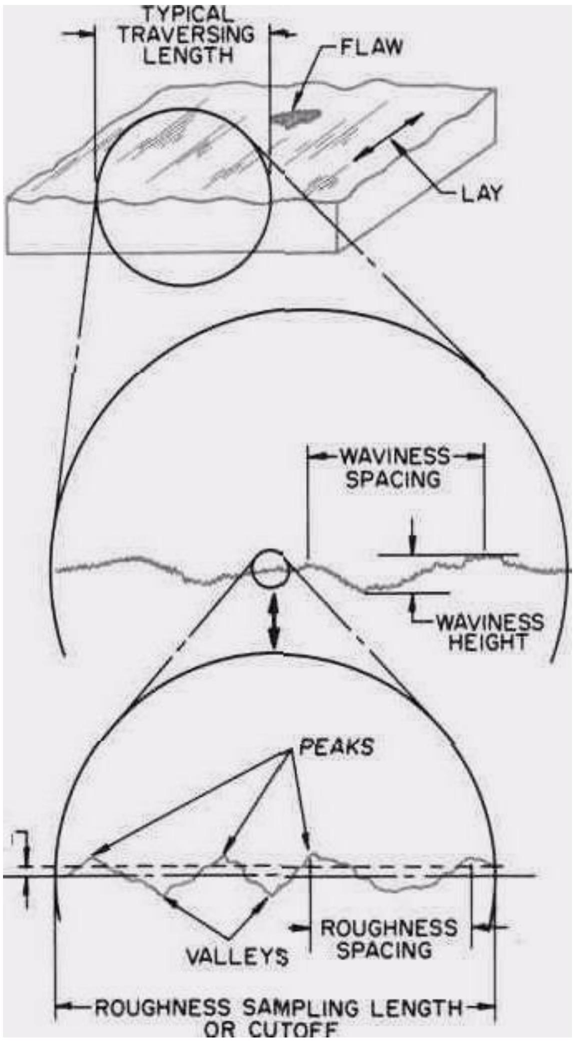


Fig. 1. Surface characteristics.

1. Control of Surface Finish

The smoothness of a machined surface is determined by a combination of factors involved in the machining process. Some of the most significant of them include: type and condition of a cutting tool used, rigidness of a machine and setup, type of material being cut, depth of cut, rate of feed, cutting speed, and kind of a cutting fluid used. The designer determines the type of surface to be produced on a given part. Standard symbols are used to indicate such surfaces. All machined surfaces have surface irregularities, including those which appear very smooth and flat. When viewed under a microscope, scratches and grooves in the form of peaks and valleys are noticeable. The surface texture is determined by such factors as width, height, and direction of surface irregularities. Fig. 1 shows surface characteristics involved in measurements of the surface finish quality.

The type of surface required for a

given product is determined by the designer. Such items as bearings, gear teeth, and pistons must have a controlled the surface quality. For example, the surface on a bearing can be excessively rough or smooth. If it is too rough, it will wear rapidly resulting in a limited life. If it is too smooth, it will not have adequate provision for oil pockets and it will be difficult to keep it lubricated, which again results in a limited life.

To require a high surface quality where it is not necessary is expensive and unprofitable. Where detailed specifications concerning the surface quality are not indicated, it means that the surface normally produced by that particular kind of machine operation is adequate.

The machinist must produce machined surfaces which meet specified standards of quality, and must be able to interpret the surface quality specifications indicated on drawings and blueprints. The machinist also must know how to determine whether machined surfaces meet surface quality specifications.

All machined surfaces including those which appear to be very flat and smooth, have surface irregularities. Under high magnification, scratches or grooves in the form of peaks and valleys are revealed. These irregularities may or may not be superimposed on larger waves. Such complex factors as height, width, and direction of surface irregularities determine the surface texture. They are specified with standard symbols on drawings.

Surface texture. Repetitive or random deviations from the nominal surface which form the three-dimensional topography of the surface. The surface texture includes roughness, waviness, lay, and flaws.

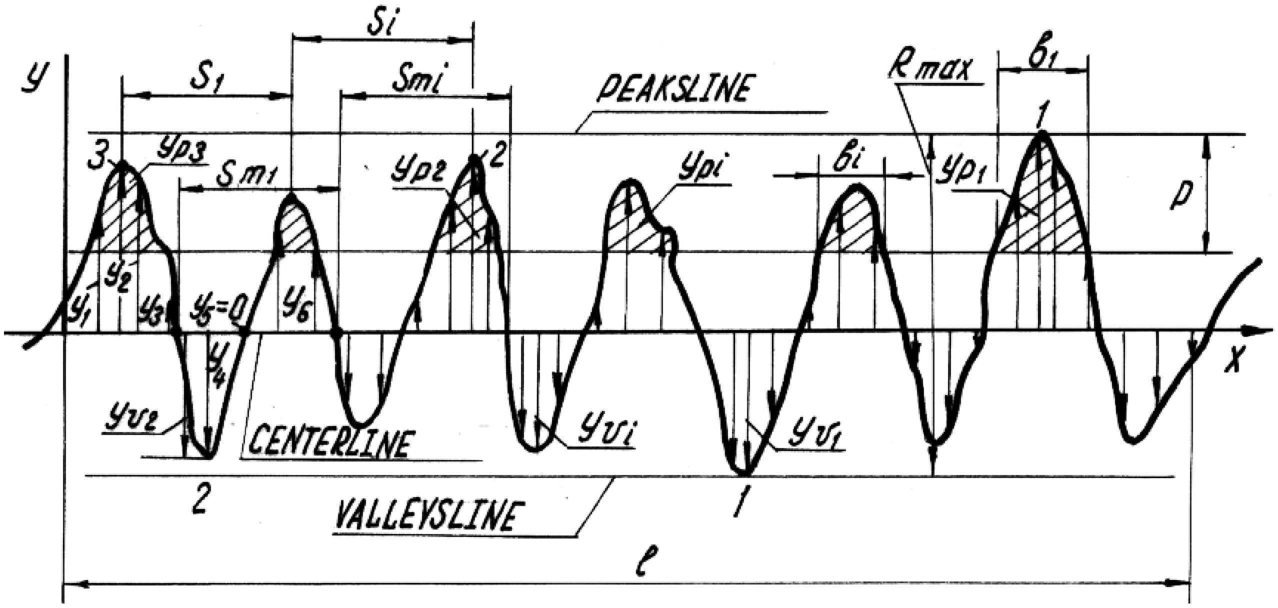


Fig. 2. Short section of a hypothetical profile divided into increments.

Profile. The profile is the contour of a surface in a plane perpendicular to the surface, unless some other angle is specified.

Centerline. The centerline is the line about which roughness is measured and is a line parallel to the general direction of a profile within the limits of the sampling length, so that the sums of the areas between it and those parts of the profile which lie on either side are equal (fig. 2).

Roughness. Roughness consists of finer irregularities in the surface texture, usually including those irregularities which result from the inherent action of the production process. These are considered to include the traverse feed marks and other irregularities within the limits of the roughness sampling length.

Roughness sampling length. The roughness sampling length ℓ is the sampling length within which the roughness average is determined. This length is chosen, or specified, to separate the profile irregularities which are designated as roughness from those irregularities designated as waviness. Roughness sampling length is measured in millimeters. Standard values are (mm): 0.08 (Ra<0.025μm), 0.25 (0.025<Ra<0.4), 0.8 (0.4<Ra<3.2), 2.5 (3.2<Ra<12.5), 8 (12.5<Ra<100). The most widely used values are: 0.8 (0.4<Ra<3.2), 2.5 (3.2<Ra<12.5).

Maximal roughness. Maximal roughness $\boldsymbol{R_{max}}$ is the distance between peak and valley lines, fig. 2. Maximal roughness is expressed in micrometers.

Height of the profile roughness on ten points. Height of the profile roughness on ten points is a sum average of absolute values of **5 highest peak**s and of **5 deepest valleys** taken within the sampling length ℓ and measured from the graphical centerline. Roughness is expressed in micrometers.

$$Rz = \frac{1}{5}\left[\sum_{i=1}^{5}|yi| + \sum_{j=1}^{5}|yj|\right], \qquad (1)$$

Roughness average. Roughness average is the arithmetic average of the absolute values of the height deviations of a measured profile taken within the sampling length and measured from the graphical centerline, fig. 2. Roughness average is expressed in micrometers.

$$Ra = \frac{1}{n}\sum_{i=1}^{n}|yi| = \frac{1}{l}\int_{0}^{l}|y(x)|dx, \qquad (2)$$

Roughness spacing. Roughness spacing is the average spacing between adjacent peaks of a measured profile within the roughness sampling length. Roughness spacing average is expressed in millimeters.

$$S = \frac{1}{n}\sum_{i=1}^{n}Si, \qquad (3)$$

Roughness spacing on the centerline. Roughness spacing on the centerline is the average spacing measured on the graphical centerline of a measured profile within the roughness sampling length. Roughness spacing average is expressed in millimeters.

$$Sm = \frac{1}{n}\sum_{i=1}^{n}Smi, \qquad (4)$$

Relative profile length. This parameter is measured on the specified level ***p*** relatively the centerline, and ***p*** is calculated in percent (5%, 10%, 15%, 20%, 25%, 30%, 40%, etc.) relative to R_{max} , fig. 2. Relative profile length is expressed in %.

$$tp = \frac{1}{l}\sum_{i=1}^{n} bi \, , \tag{5}$$

where ℓ is the roughness sampling length.

Gegenerally p = 30%. For example, for t_{30} p = 30% and for R_{max} = 10 µm $p = 10\times\cdot 0.30 = 3$ µm.

Cutoff. The cutoff is the electrical response characteristic of the roughness average measuring instrument which is selected to limit the spacing of the surface irregularities to be included in the assessment of roughness average. The cutoff is rated in millimeters.

Checking Surface Texture

The roughness of the surface may be checked with several types of instruments. The most widely used is an electrical type instrument employing a stylus which passes over an irregular surface. The motion of the stylus is amplified and the average roughness is indicated in µm (mkm). This instrument is known as a **profilometer,** fig. 3.

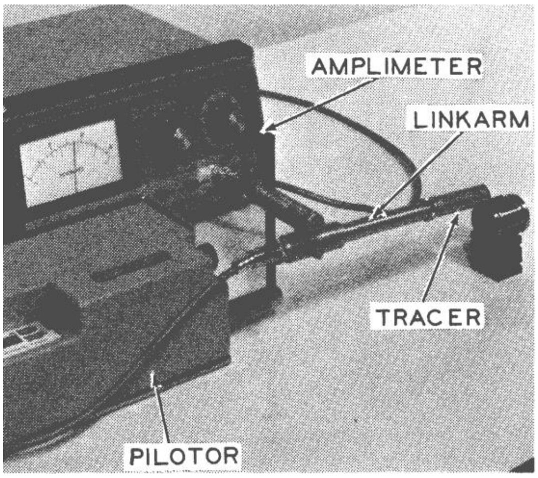


Fig. 3. Profilometer-amplifier shows arithmetical (AA) roughness height on a micrometer meter as the tracer is moved along the workpiece.

Measurement with the profilometer is continuous, showing the variation in average roughness taken from a reference line, as in the drawing, fig. 4.

The roughness height is expressed in micrometer (µm) as a simple arithmetical average (AA deviation, measured normal to the center line. NOTE: In former standards, the roughness height was expressed in mkm as the root mean average (RMS) deviation, measured normal to the center line (fig. 4).

The quality of a surface is determined largely by the production method used to produce the surface. The range of surface finish may vary greatly with different production processes.

In selecting the required surface finish for a particular part, the engineer bases his decision on his past experience with similar parts, on field service data, or on engineering tests.

The engineer's choice is based on such factors as the size and function of parts, type of loading, speed and direction of movement, operating conditions, physical characteristics of both materials in contact, type and amount of a lubricant required, temperature, and possible stress reversals to which parts may be subjected.

The range of machining operations may vary a great deal. Where a specific surface quality is required, a method which will produce this surface **most economically** is selected. To secure quick measurements that are required by production methods, measuring devices that have a fixed shape or size are used. The use of such instruments cuts the inspection time to a minimum; in fact, much of this type of gaging can be done by machine operators.

A = 4	A^2 = 16
B = 16	B^2 = 256
C = 22	C^2 = 484
D = 15	D^2 = 225
E = 28	E^2 = 784
F = 20	F^2 = 400
G = 25	G^2 = 625
H = 19	H^2 = 361
I = 30	I^2 = 900
J = 11	J^2 = 121
K = 21	K^2 = 441
L = 15	L^2 = 225
M = 5	M^2 = 25
231	4863 Totals

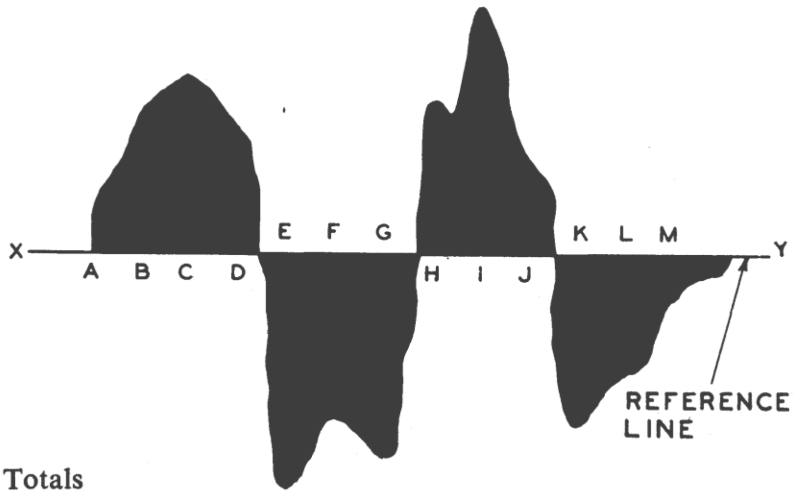


Fig. 4. The arithmetical average and rms values used in determining surface roughness.
Arithmetical average (AA) = 231/13 = 17.7 μm.
Root mean average (RMS) = $\sqrt{4863/13}$ = 19.3 μm.

Comparison of surface qualities can be done by touch and sight. Standard specimens that have been previously checked with a surface measuring instrument may be used (fig. 5). A comparison can be made between the surface being checked and the specimen by dragging a fingernail over both surfaces. When the feel is the same, the roughness (in micrometers of height) is approximately the same.

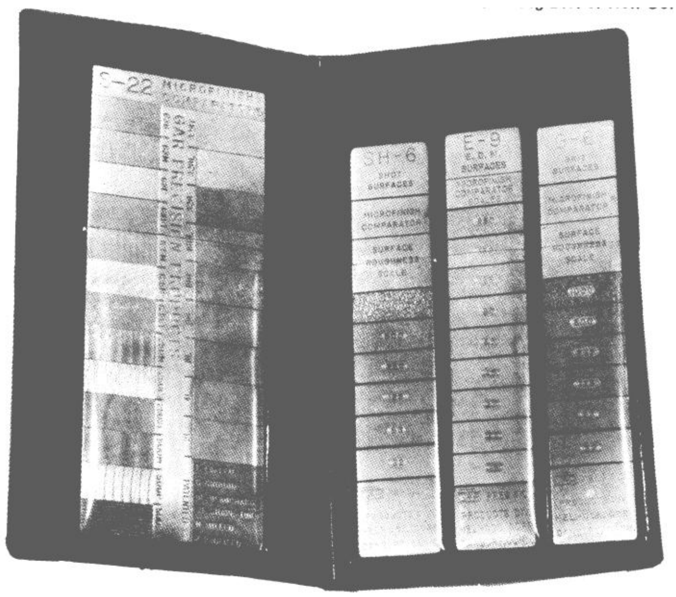


Fig.5. Surface finish comparator contains reference scales for machined, grit blast, shot blast, and electrical discharge machined surface finishes.

Also, with experience, the visual method quickly determines the approximate roughness value of a workpiece. Such methods can be used on parts that do not require close tolerances. For the best results in determining roughness, one should always compare the surfaces obtained with the **same machining process**. Each type of machining produces a different pattern of surface irregularities (tool marks). Two surfaces of the same micrometer roughness produced by different machining processes (i.e., ground and turned) appear to differ in roughness because of the way light is reflected from surface irregularities. The brighter surface is not necessarily the smoother one. Profilometers and similar measuring instruments are advised for short run jobs where fast production is not required.

Waviness

Waviness is the more widely spaced component of the surface texture (fig.1). Unless otherwise noted, waviness is to include all irregularities whose spacing is greater than the roughness sampling length and less than the waviness sampling length. Waviness may result from such factors as machine or work deflections, vibration, chatter, heat treatment, or warping strains. Roughness may be considered superimposed on a «wavy» surface.

Waviness height. The waviness height is the peak-to-valley height of the modified profile from which the roughness and flaws have been removed by filtering, smoothing, or other means. The measurement is to be taken normal to the normal profile within the limits of the waviness sampling length and expressed in millimeters.

Waviness spacing. The waviness spacing is the average spacing between adjacent peaks of the measured profile within the waviness sampling length.

Lay. Lay is the direction of the predominant surface pattern, ordinarily determined by the production method used.

Flaws. Flaws are unintentional irregularities which occur at one place or at relatively infrequent or widely varying intervals on the surface. Flaws include such defects as cracks, blow holes, checks, ridges, scratches, etc. Unless otherwise is specified, the effect of flaws shall not be included in the roughness average measurements. Where flaws are to be restricted or controlled, a special note as to the method of inspection should be included on the drawing or in the specifications.

Application of Surface Finish Symbols

Surface quality is designated with a surface finish symbol and ratings. The symbol is similar to a check mark, but with a horizontal extension line added, fig.6. The long leg of the check-like symbol is to the right as the drawing is read. If only the roughness height is designated, the horizontal extension line may be omitted.

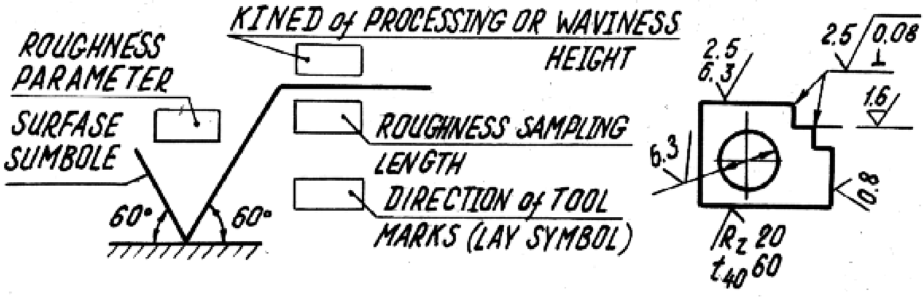


Fig. 6. Application of surface finish symbols.

The point of the surface symbol is located on the line indicating the surface specified. It also may be located on an extension line or leader pointing to the surface specified, as in fig.6. Symbols used with the surface symbol to indicate lay are shown in table 1.

Table 1. Lay symbols

Lay symbol	Meaning
=	Lay is approximately parallel to the line representing the surface to which the symbol is applied.
⊥	Lay is approximately perpendicular to the line representing the surface to which the symbol is applied.
×	Lay is angular in both directions to the line representing the surface to which the symbol is applied.
M	Lay is multidirectional.
C	Lay is approximately circular relative to the center of the surface to which the symbol is applied.
R	Lay is approximately radial relative to the center of the surface to which the symbol is applied.
P	Lay is particulate, nondirectional, or protuberant.

Surface quality ratings for various characteristics such as roughness, waviness, and lay are positioned specifically in relation to the surface symbol fig. 7. The relative location of these specifications and ratings are indicated in table 2.

Table 2. Application of surface texture values to symbol

Symbol	Meaning
	Roughness average rating is placed on the left of the long leg. The specification of only one rating will indicate the maximum value and any smaller value will be acceptable. Specified in micrometers.
	The specification of maximum and minimum roughness average values indicates a permissible range of roughness. Specified in micrometers.
	Maximum waviness height rating is the first rating placed above the horizontal extension. Any smaller rating will be acceptable. Specify in millimeters. Maximum waviness spacing rating is the second rating placed above the horizontal extension and to the right of the waviness height rating. Any smaller rating will be acceptable. Specified in millimeters.
	Material removal by machining is required to produce the surface. The basic amount of stock provided for material removal is specified on the left of the short leg of the symbol. Specified in millimeters.
	Removal of material is prohibited.
	Lay designation is indicated by the lay symbol placed on the right of the long leg.
	Roughness sampling length or cutoff rating is placed below the horizontal extension. When no value is shown, 0.8 mm applies. Specified in millimeters.
	Where required maximum roughness spacing shall be placed on the right of the lay symbol. Any smaller rating will be acceptable. Specified in millimeters.

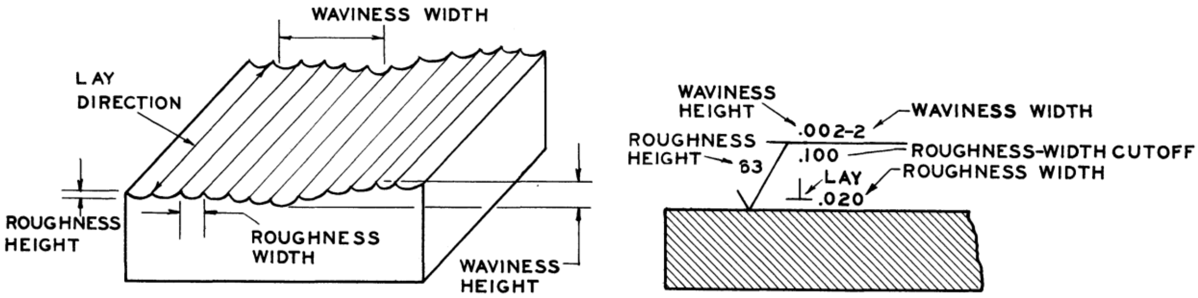


Fig. 7. Surface characteristics and symbols for indicating their maximum values.

Designations for Roughness Height

The roughness average, according to the ISO standard, is expressed in micrometers as the simple **arithmetical average** (AA) deviation measured normal to the centerline. In previous standards the roughness height was expressed in micrometers as the **root mean square average** (RMS) deviation measured normal to the centerline. Certain instruments are equipped with a selector switch for selecting either the RMS or the AA reading.

Roughness measuring instruments calibrated for AA values will indicate approximately 11 percent lower for a given surface than those calibrated for RMS average values (fig. 4). However, because the absolute limit of roughness for satisfactory functioning of a surface is indefinite, many manufacturers adopt AA ratings without changing the RMS values indicated on older drawings. For most surface measurement applications, the difference between the two values is of no consequence.

In order to eliminate error or confusion in the use of various stylus instruments, standards are included in ANSI B46.1-1978. For instruments indicating a numerical value only, a spherical-tip stylus with a 10 micrometer radius tip is standard. The accuracy of instruments for surface roughness measurement should be checked periodically by measuring a precision reference specimen.

Flatness Measurement

Flatness is very important to the accuracy of gage blocks and certain other gages, micrometers, parallels, and other precision tools. It is equally important to proper functioning of flat metal-to-metal assemblies which must be leak-free without use of sealing materials. This degree of flatness goes well beyond the capacity of dial indicators or other conventional measuring tools to detect.

Interferometry, using the interference of two beams of light for measurement, is capable of measuring flatness to 25 millionths of a millimeter. Interferometry is the interpretation of the fringe patterns that result when rays of light interfere with each other (fig. 8). For this type of measurement there is a choice of two classes of tools: (1) simple inexpensive optical flats or (2) complex interference instruments, generally called **interferometers**. Optical flats utilize interferometry and are relatively inexpensive tools used for measuring flatness.

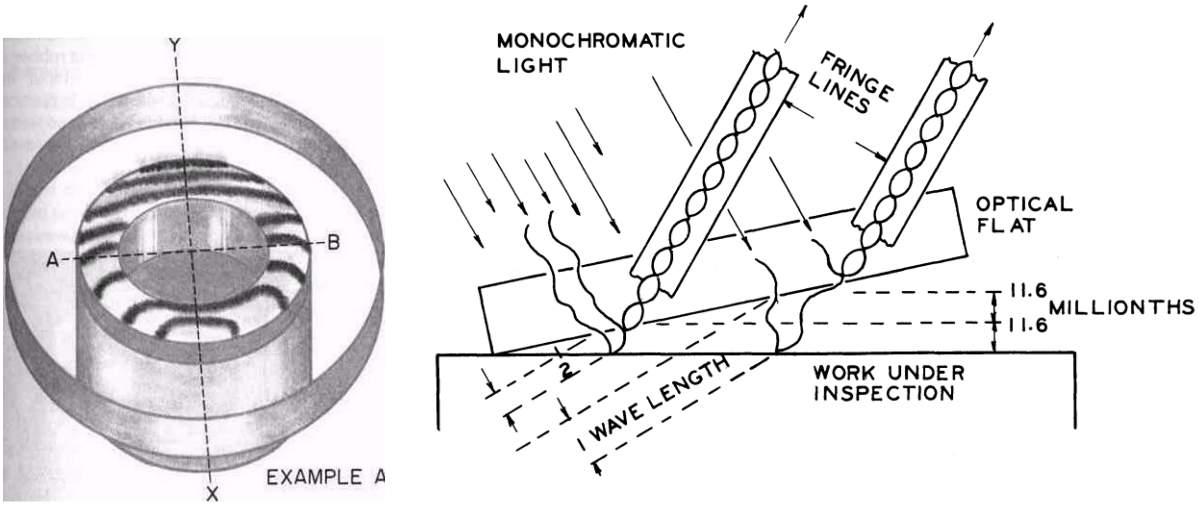


Fig. 8. Pattern of dark bands produced by a rotating seal that is not flat. The greatest variation from flatness is across the approximate center, where the center is higher than the outer edges by 1 1/2 scale lines or 442 millionths of a millimeter.

Optical flats (fig. 8) are quartz or glass lenses that have been polished accurately flat on one or both surfaces. When both surfaces are polished, they are known as **optical parallels.** They range in size from 25 mm diameter, 13 mm thick, to 300 mm diameter, 70 mm thick, and larger. A choice of three grades provides accuracies of 25, 50, or 100 millionths of a millimeter.

The precision surface of the optical flat facing the work is both transparent and light reflecting. Because of this, light waves striking this surface are effectively split into two light waves, one passing through and one reflecting back. When two reflected light waves cross or interfere with each other, they become visible as dark bands (fig. 8). This occurs when the surface of the optical flat and the surface being measured are out of parallel by one half of a wavelength, or multiples thereof, of the light being used.

Monochromatic light is preferred for most interferometry. Colors of light vary with their wave lengths. White light consists of all visible wave lengths combined. Monochromatic light is of one color only. Monochromatic fringes are easier to see, to count, and to evaluate in terms of millionths of a millimeter than white light. The light source used for practical shop work is helium, which has a wave length of 589 millionths of a millimeter. Thus, ***each dark band provides*** a measuring unit of 294.5 millionths of a millimeter.

Fundamentally, the functioning part of an optical flat is the surface facing the work. It is both transparent and capable of reflecting light. Therefore all light waves that strike the surface are in effect, split in two longitudinally. One part is reflected back by the surface of the flat. The other part passes through and is reflected back by the surface under inspection as illustrated (fig. 8). Whenever the reflected split portions of two light waves cross each other (interfere), they become visible and produce dark bands. This happens whenever the distance between the reflecting surfaces is one-half of a wave length or multiples thereof.

Flat surfaces out of parallel in one axis produce a pattern of dark bands at right angles to that axis. Diagonal bands result when the surfaces are out of parallel in both axes. Convex or concave surfaces produce a pattern of curved bands.

When the optical flat rests on the work under monochromatic light a thin, slightly sloping space (wedge) of air separates the surfaces. The wedge is stable enough for band reading because of minute dust particles or lint.

If the air wedge is about 883.5 millionths of a millimeter higher on one side than the other, three bands will appear across the work surface, one band for each 294.5 millionths of a millimeter of elevation (294.5 millionths of a millimeter = =0.2945 μm ≈ 0.3 μm). In other words, the number of bands between two points on a surface can be used to determine the relative height difference in millionths of a millimeter between the flat and the surface by multiplying the number of bands between the points by 0.3 μm.

If a work surface is not exactly flat but slightly cylindrical, the sloping space between the work and the optical flat would contain regions of uniform height, but they would not occur in straight lines (fig. 9). The interference pattern would therefore show curved bands.

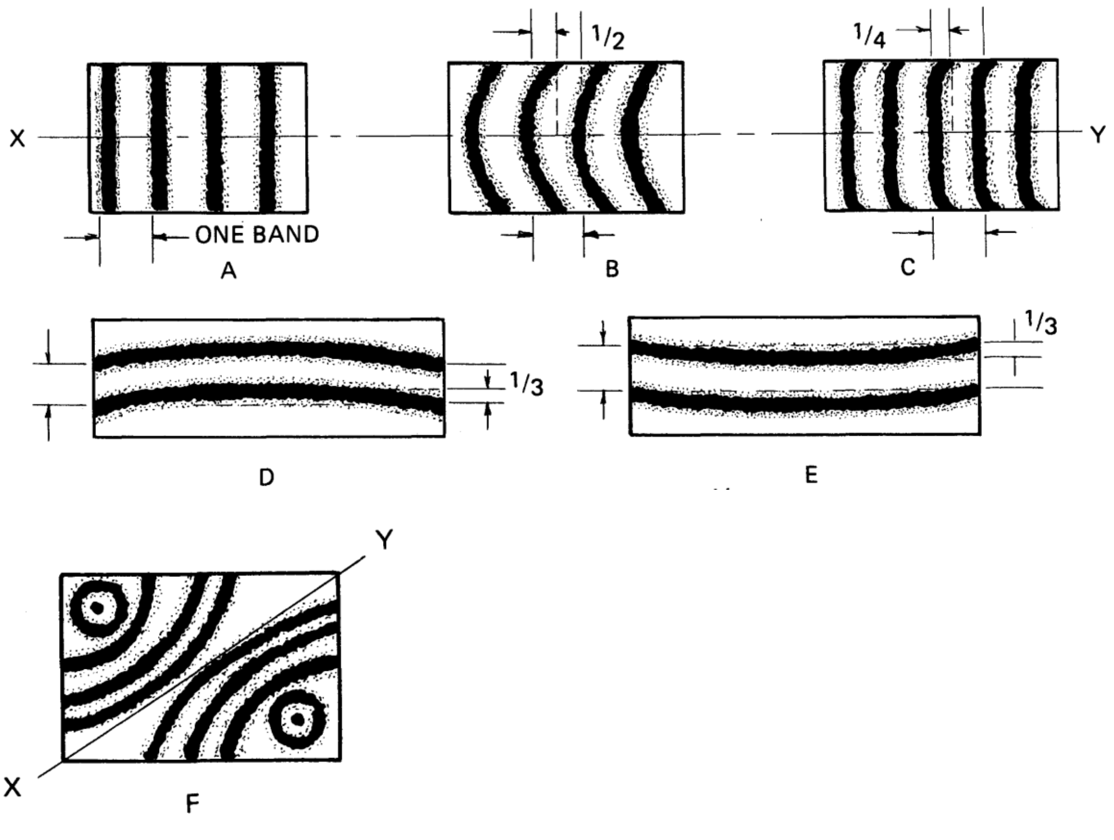


Fig. 9. The extent of surface deviations from absolute flatness. (A) Wedge of 1.2 μm will show four bands. If surfaces of both flat and work are perfect planes, the bands will appear straight and equidistant. (B) Surface is convex by 1/2; low along outer edge by 0.15 μm. (C) Surface flat across the center but low along the outer edges by 0.08 μm. (D) Surface is convex by 1/3 band. (1/3 of 0.3 μm equals 0.1 μm.) Outer edges are low by 0.1 μm. (E) Surface is concave by 1/3 band or 0.1 μm. (F) Shows two points of contact which are high points on the surface. The center along line x-y is low by $4^1/_2$ bands or 1.35 μm.

Tasks for performing work

1. Make a drawing of a part.
2. Measure and draw all surface texture and the roughness of the surfaces.
3. Measure and write down all roughness characteristics.
4. Write down all determined characteristics in symbols of the roughness surface.
5. Define the accordance of roughness surface and size accuracy (grade of tolerances).
6. Measure and write down all roughness characteristics available by other methods.
7. Draw the **schemes of measurements** and write down the names of equipment.

Laboratory work №9
"Inspection of the surface form and disposition of surfaces"

The purpose of work:
1. To get acquainted with the equipment and methods of inspection of the surface form and disposition of surfaces.
2. To study the basic operations of inspection of the surface form and disposition of surfaces.
3. To estimate the accuracy of controlled parts and write down the accordance designations.

Equipment and materials:
1 Post tool holder with a dial indicator.
2. Tool maker centers.
3. Prisms.
4. Parts.

Basic rules on the theme of work

1. Inspection of the surface form

Analysis of the geometrical accuracy of a part is based on the comparison of the actual surface form with the nominal surface form (the surface which does not have errors of surface and has an ideal form.)

The tolerance of deviation of the form and disposition of surfaces depends on the geometrical accuracy of a part and the value of the part length or the length of a specified site. The geometrical accuracy of a part depends on the purpose of the part.

There are16 degrees of accuracy which are established for each kind of the tolerance of the form and disposition of surfaces. The numerical value of the tolerances one degree to another is changed with a factor of increase 1.6. Degrees of accuracy 9 - 10 are made by turning, shaping and milling; degrees of accuracy 7 - 8 are achieved by medium accurate turning, shaping and milling; degrees of accuracy 5 - 6 are made by grinding.

The following levels of the relative geometrical accuracy are established depending on the ratio between a size tolerance and tolerances of the form or surface dispositions: ***A*** - normal relative geometrical accuracy (tolerances of the form or surface dispositions make up approximately ***60 %*** of the size tolerance); ***B*** – an increased relative geometrical accuracy (the ratio is ***40 %***); ***C*** – a high relative geometrical accuracy (the ratio is ***25 %***.)

Normal relative geometrical accuracy (***A***) corresponds to 12-th degree of the ***geometrical accuracy*** and to 11-th grade of the tolerance. For example, for the size of 20h11 mm the ***tolerance*** is equal to 130 μm, the ***tolerance of roundness*** for the normal relative geometrical accuracy (A) is Δ_s = 130×0.60 = 78 µm. For ***12-th degree of the geometrical accuracy*** tolerance of roundness is 80 µm (Table 2, column 12-th degree of accuracy and stroke 18…30 mm).

Increased relative geometrical accuracy (***B***) corresponds to 9-th degree of geometrical accuracy and to 9-th grade of tolerance. For example, for the size of 20h9 mm the ***tolerance*** is equal to 52 µm, the ***tolerance of roundness*** for increased relative geometrical accuracy (B) is Δ_s = 52×0.40 = 20.8 µm. For 9-th degree of geometrical accuracy the tolerance of roundness is 20 mkm (Table 2, column 9-th degree of accuracy and stroke 18…30 mm).

High relative geometrical accuracy (***C***) corresponds to 6-th degree of geometrical accuracy and to 7-th grade of tolerance. For example, for the size of 20h7 mm the ***tolerance*** is equal to 21 µm, the ***tolerance of roundness*** for high relative geometrical accuracy (C) is Δ_s = 21×0.25 = 5.25 µm. For ***6-th degree of geometrical accuracy*** the tolerance of roundness is 6 µm (Table 2, column 6-th degree of accuracy and stroke 18…30 mm).

Tolerances of the form or surface dispositions are specified only for functional or technological reasons (when they should be less than the size tolerance.)

Deviation from straightness is the greatest deviation of an actual surface form from an adjoining straight. The adjoining straight is a straight which touches the surface but does not cross the actual profile of a part, fig. 1. The adjoining straight has to set so that the deviation from one to the farthest point of the actual profile will be least within the limits of a measured section. This measurement is made in any direction and on any site of the part if it is not specified. The measured deviation is compared with the tolerance of deviation from straightness, table 1.

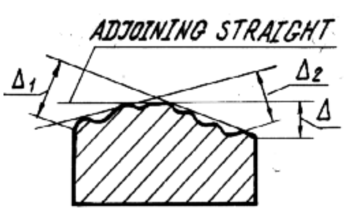


Fig. 1. Adjoining straight: $\Delta < \Delta_1 < \Delta_2$

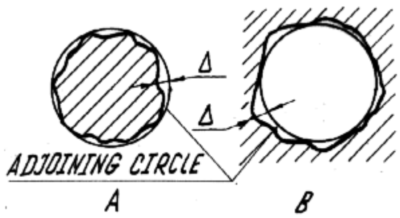


Fig. 2. Adjoining circle: A- draw-out; B- draw-in.

Deviation from flatness is the greatest deviation of an actual surface form from an adjoining plane. The adjoining plane is a plane which touches the surface but does not cross the actual profile of a part. The adjoining plane has to set so that the deviation from one to the farthest point of actual profile will be least within the limits of a measured section.

Deviation from roundness is the greatest deviation of an actual surface form from an adjoining circle. The adjoining circle is a draw-out circle for an external surface (shaft) and a draw-in circle for an internal surface (hole.) The draw-out circle is a circle, which has a minimum diameter but does not cross the actual profile of a part, fig. 2, A. The draw-in circle is a circle, which has a maximum diameter but does not cross the actual profile of the part, fig. 2, B. This measurement is made on any cross section of a part if it is not specified. The measured deviation is compared with the tolerance of deviation from the roundness. The tolerance of deviation from the roundness depends on the geometrical accuracy of a part and a diameter size. The geometrical accuracy of a part depends on the purpose of a part, table 2.

Table 1. Tolerances of deviations from straightness and a plane, μm.

Size, mm	Degree of accuracy							
	5	6	7	8	9	10	11	12
0 - 10	1.6	2.5	4	6	10	16	25	40
10 - 16	2	3	5	8	12	20	30	50
16 - 25	2.5	4	6	10	16	25	40	60
25 - 40	3	5	8	12	20	30	50	80
40 - 63	4	6	10	16	25	40	60	100
63 - 100	5	8	12	20	30	50	80	120
100 - 160	6	10	16	25	40	60	100	160
160 - 250	8	12	20	30	50	80	120	200
250 - 400	10	16	25	40	60	100	160	250
400 - 630	12	20	30	50	80	120	200	300
630 - 1000	16	25	40	60	100	160	250	400
1000 - 1600	20	30	50	80	120	200	300	500
1600 - 2500	25	40	60	100	160	250	400	600
2500 - 4000	30	50	80	120	200	300	500	800
4000 - 6300	40	60	100	160	250	400	600	1000
6300 - 10000	50	80	120	200	300	500	800	1200

Deviation from cylindricness is the greatest deviation of an actual surface form from an adjoining cylinder. The adjoining cylinder is a draw-out cylinder for an external surface (shaft) and a draw-in cylinder for an internal surface (hole.) The draw-out cylinder is the cylinder which has a minimum diameter but does not cross the actual profile of a part. The draw-in cylinder is the cylinder which has a maximum diameter but does not cross the actual profile of a part.

Table 2. Tolerances of deviation from the roundness, cylindricness, a profile of a longitudinal section, μm.

Size, mm	Degree of accuracy							
	5	**6**	**7**	**8**	**9**	**10**	**11**	**12**
0 - 3	2	3	5	8	12	20	30	50
3 - 10	2.5	4	6	10	16	25	40	60
10 - 18	3	5	8	12	20	30	50	80
18 - 30	4	6	10	16	25	40	60	100
30 - 50	5	8	12	20	30	50	80	120
50 - 120	6	10	16	25	40	60	100	160
120 -250	8	12	20	30	50	80	120	200
250 - 400	10	16	25	40	60	100	160	250
400 - 630	12	20	30	50	80	120	200	300
630 - 1000	16	25	40	60	100	160	250	400
1000 - 1600	20	30	50	80	120	200	300	500
1600 - 2500	25	40	60	100	160	250	400	600

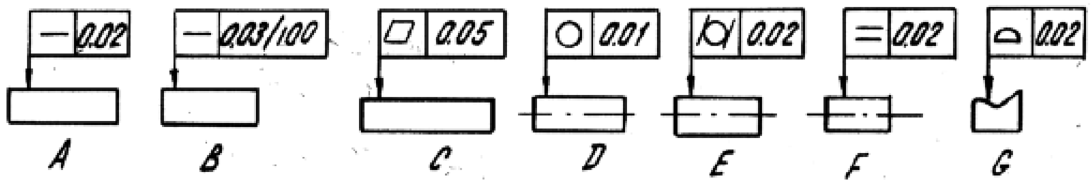


Fig. 3. Deviations: A - deviation from the straightness on the full length of the part; B - deviation from the straightness on the length of 100 mm; C - deviation from the plane; D - deviation from the roundness; E - deviation from the cylindricness; F - deviation from the profile of a longitudinal section; G - deviation of a form of a specified surface.

2. Deviations of disposition of surfaces

Deviation of disposition of a surface or profile is a deviation of the actual surface (profile) from its base disposition. Deviations of examined surfaces and base surfaces must be excepted. These surfaces are replaced by adjoining surfaces and axes, planes of symmetry and the centers of adjoining surfaces are considered axes, plates of symmetry and the centers of actual surfaces.

Deviation from parallelism of plates is the difference of the largest and the smallest distances between the examined and base surfaces within the limits of a specified section, fig. 4.

Deviation from parallelism of axes in space is the geometry sum of deviations from parallelism of projections of axes in two mutually perpendicular plates. One of these plates passes through the base axis and point of crossing of the examined and base axes, fig. 4.

Deviation from the perpendicular of surfaces can be measured both in millimeters and in an angular value. In the most cases, this deviation is measured in millimeters using a dial indicator with a tool post holder and a sleeve, fig. 4.

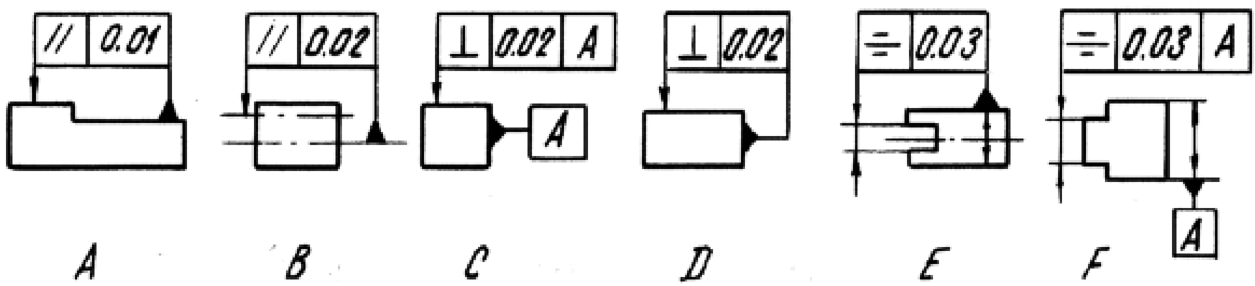


Fig. 4. Deviation of disposition of a surface or profile: A - deviation from parallelism of plates; B - deviation from parallelism of axes in space; C - deviation from perpendicular of surfaces; D - deviation from perpendicular of surfaces; E - deviation from symmetry to a base plane; F - deviation from symmetry to a base plane.

Deviation from coaxiality is the greatest distance between the axis of the examined surface of rotation on the length of the normalized site (fig. 5). The tolerance zone of coaxiality is an area in space limited by the cylinder, whose diameter is equal to the tolerance of coaxiality of the diametrical expression T, and the axis coincides with a base axis.

Deviation from symmetricity to the base plane is the greatest distance between the plane of symmetry of an examined surface and the base plane of symmetry within the limits of the normalized site, fig. 4.

Item deviation (it is designated by symbol ⨁) is the greatest deviation of the real disposition of an element (its center, axis or plate of symmetry) from its nominal disposition, fig. 8.

Radial palpitation of the rotation surface relative to the base axis grows out of joint display of the deviation from roundness of examined section and the deviation of its center relative to the base axis. It is equal to the difference of the greatest and least distances from the points of the real profile of the rotation surface to the base axis in the section perpendicular to this axis. The complete radial palpitation is determined within the limits of the normalized site, fig. 5.

Table 3. Tolerances of coaxiality, symmetricity, axes cross and radial palpitation

Base size, mm	Degree of accuracy							
	5	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	Tolerance, μm							
0 - 3	5	8	12	20	30	50	80	120
3 - 10	6	10	16	25	40	60	100	160
10 - 18	8	12	20	30	50	80	120	200
18 - 30	10	16	25	40	60	100	160	250
30 - 50	12	20	30	50	80	120	200	300
50 - 120	16	25	40	60	100	160	250	400
120 - 250	20	30	50	80	120	200	300	500
250 - 400	25	40	60	100	160	250	400	600
400 - 630	30	50	80	120	200	300	500	800
630 - 1000	40	60	100	160	250	400	600	1000
1000 - 1600	50	80	120	200	300	500	800	1200
1600 - 2500	60	100	160	250	400	600	1000	1600
Note: 1. Tolerances of coaxiality, symmetricity and axes cross are showed in diametrical expression. 2. The base size is the examined size.								

Face palpitation (complete) is the difference of the greatest and least distances from the points of the real face surface to a plane, which is perpendicular to the base axis. Sometimes the radial palpitation is determined in the face surface section by the cylinder of a specified diameter d, fig. 6.

Radial palpitation of the rotation surface relative to a common axis grows out of joint display of the deviation from roundness of an examined section and the deviation of its center relative to the common axis, fig. 7.

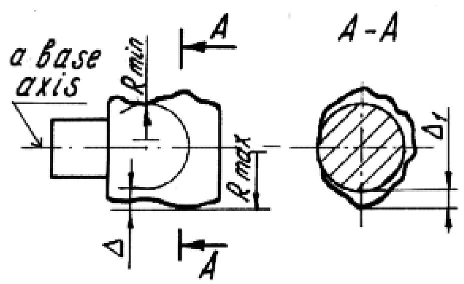


Fig.5. Complete radial palpitation of the rotation surface relatively to the base axis.

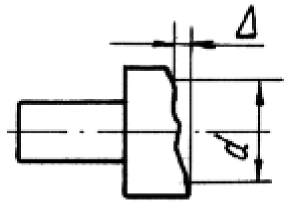


Fig.6. Face palpitation relative to a common axis.

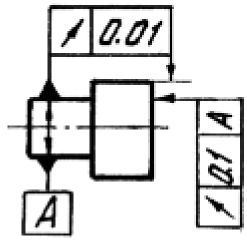


Fig.7. Radial and face palpitations relative to a common axis.

Dependent tolerance is the variable tolerance of disposition of a surface or form. Its minimal value is specified on the drawing which is supposed to be exceeded by a value appropriate to the deviation of the actual size of a surface of a part from the maximum material limit (the greatest limiting size of the shaft or the least limiting size of the hole), fig. 8.

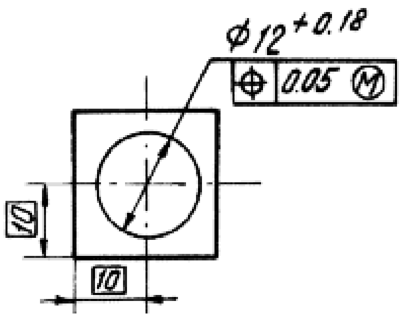


Table for explanation of dependent tolerance

Possible actual diameter of the hole, mm	12.0	12.01	12.02	12.10	12.18
Full value of the dependent item tolerance, mm	0.05	0.06	0.07	0.15	0.23

Fig. 8. Designation of the dependent item tolerance and a table for its explanation.

The dependent tolerances of disposition of surface and form are nominated basically when it is necessary to supply an assembly of matting parts simultaneously on several surfaces. The dependent tolerances are usually controlled by complex gages.

3. Designation of tolerances of the form and the surface disposition

The kind of tolerance of the form and disposition of a surface are designated on the drawing by marks (graphic symbols). The mark (table 4) is entered in a framework in the first box, the numerical meaning of the tolerance in millimeters is written in the second box, fig. 9. If it is necessary the letter designation of the base (base surface) is written in the third box. The framework is united to an element, to which the tolerance is related, with a continuous line, which comes to an end by a pointer. If the tolerance is related to an axis or plane of symmetry the connecting line should be continuation of the size line. If the tolerance concerns a common axis or plane of symmetry the connecting line is drawn to the common axis.

Table 4. Marks of tolerances of form and surface disposition

Group of tolerances	Kind of tolerance	Mark
Tolerances of form	Tolerance of straightness	—
	Tolerance of planeness	□
	Tolerance of roundness	O
	Tolerance of cylindricness	/O/
	Tolerance of profile of longitudinal section	═
Tolerances of the surface disposition	Tolerance of parallelness	//
	Tolerance of perpendicularity	⊥
	Tolerance of inclination	∠
	Tolerance of coaxiality	◎
	Tolerance of symmetricyty	÷
	Tolerance of item	⊕
	Tolerance of axes crossing	×
Total tolerances of form and surface disposition	Tolerance of radial palpitation	↗
	Tolerance of face palpitation	↗
	Tolerance of full radial palpitation	↗↗
	Tolerance of full face palpitation	↗↗
	Tolerance of the form of a specified profile	⌒
	Tolerance of the form of a specified surface	⌓

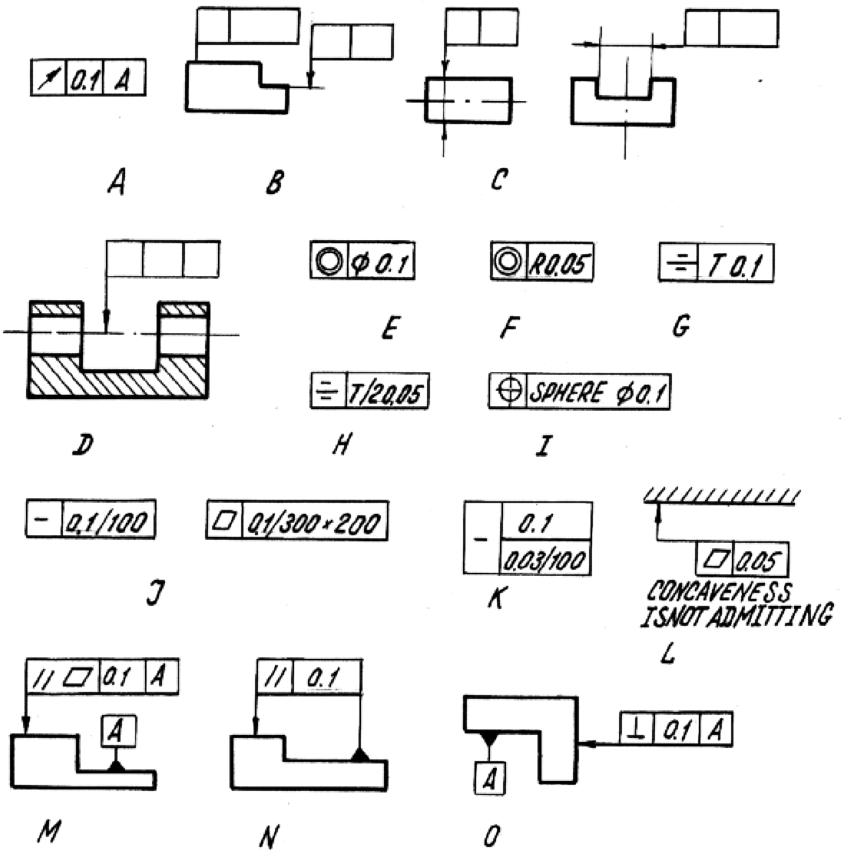


Fig. 9. Designation of tolerances of the form and of the disposition of surface.

In front of the numerical value of the tolerance it is necessary to write down a symbol: Ø - the tolerance is specified by its diameter (fig. 9, E); R - the tolerance is specified by its radius (fig. 9, F); T - the tolerance is specified in diameter expression (fig. 9, G) (for the tolerances of symmetry, crossing of axes, the form of a specified surface, item); T/2 - the same tolerances are specified in radius expression (fig. 9, H); the word "sphere" and the symbols Ø or R if the tolerance zone is spherical (fig. 9, I).

If the tolerance is related to a site of a surface of specified length (area), its value is underlined behind the tolerance, separating with an inclined line. If the tolerance is specified to the whole length and to a site of a surface of specified length the tolerance of specified length is underlined below the tolerance of the whole length.

The total tolerances of the form and disposition of a surface for which special symbols are not established, are designated by marks of the compound tolerances: the tolerance symbol of the disposition of a surface is marked first, then the tolerance symbol of the form is marked.

The base is designated with a black triangle, which is related to the framework of the tolerance. In most cases, the base is designated with a letter. In this case, it is necessary that: sections and kinds are designated first with letters in the alphabetic order without the misses and recurrences, and then the bases are designated continuing the alphabet.

The dependent tolerance is designated by letter M in a circle. It is written: after numerical value of the tolerance, if the dependent tolerance is connected to the actual size of a surface, fig. 10, A; after a letter designation of base (fig. 10, B) or without a letter designation of base (fig. 10, C) in the third part of a framework, if this tolerance is connected to the actual sizes of the base surface; after numerical value of the tolerance and after a letter designation of the base or without a letter designation of the base if the dependent tolerance is connected to the examined and to the base element, fig. 10, D.

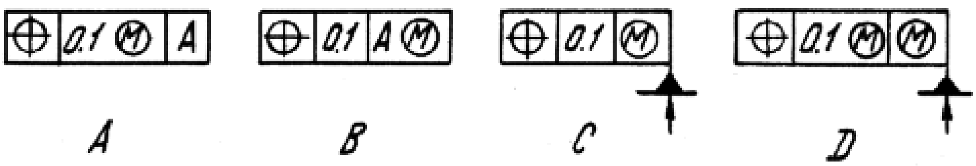
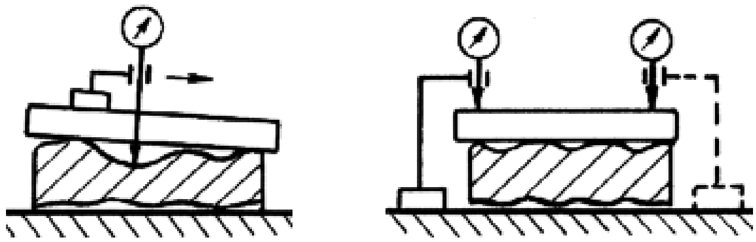


Fig. 10. Designation of dependent tolerances.

4. Measurements of deviations of the form and surface dispositions

The deviations of the form are measured with universal and special measuring devices. A special measuring surface plate from cast iron and firm stone breeds (in the basic granite), **straight-edges**, master straight-edges, **parallel-plane** precision gage blocks, optic-mechanical devices are used for these purposes. For measurement of the deviation from straightforwardness (straightness) a parallel-plane ruler (plate) is put on a checked surface (fig. 11, A). This plate carries out the role of an adjoining straight line. A tool post holder (rack) with an indicator is put on this plate, and the tip of the indicator touches the checked surface. The tool post holder with the indicator is moved on the plate along the part. The difference of the greatest deviations of an indicator hand is the deviation from straightness.



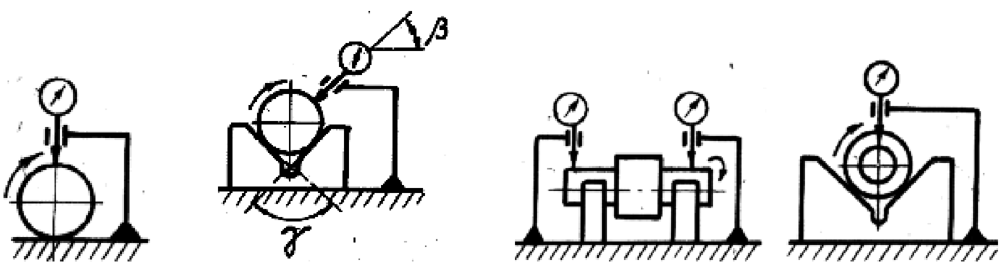
A B

Fig. 11. Schemes of measurements of deviations from straightness (A) and parallelism (B).

For measurement of deviations from **parallelism** a similar scheme is used, but the part and rack are put on a parallel-plane plate, and the tip of the indicator touches the surface of the plate (fig. 11, B). A deviation from parallelism is the difference of the greatest and least deviations of the indicator hand when it moves along a part. The deviation from the plane can be supervised on the stain of contact.

The laser beam is used in optic-mechanical devices as an exemplary straight line. The coordinate measuring machine is applied too exact measurements of deviations from parallelism. The tip of the machine scans the checked surface. The coordinates of the surface are entered into computer, which creates a virtual adjoining plane to the virtually created scanned surface. The maximal deviation of these virtual surfaces is the deviation from the plane. The round-gauge works similarly, the record is done in polar coordinates.

Indicators with prisms and a special support are used for measurement of deviations from roundness. One-point (fig. 12, A) and two-point devices cannot measure the deviation from roundness with an odd number of sides. The basing on a prism (V-block) is used in this case (fig. 12, B). Indications of the device are multiplied by the reproduction factor, which depends on the number of sides and the prism corner.



A B C D

Fig. 12. Schemes of measurements of deviations from roundness (A, B), coaxiality(C) and radial palpitation (D).

Fastening of the shaft at the centers is used for measurement of the deviation from roundness, radial palpation and coaxiality (fig. 12). Two indicators are mounted on the checked and base surfaces simultaneously for checking of the deviation from coaxiality (fig. 12, C). The radial palpation relative to the base surface is the difference between the simultaneous indications of indicators.

The deviation from coaxiality of holes in the case of parts is measured with the help of a mandrel mounted in these holes. Set square or the vertical moving of the indicator on the rack is used for measurement of deviations from the perpendicular.

Tasks for performing work

1. Draw the drawing of part №1 (long step shaft with end centers holes).
2. Measure and write down all necessary sizes of the step shaft and roughness of the surfaces.
3. Write down the symbols of ***deviation from roundness***, symbols of ***radial palpation*** and ***coaxiality*** of all surfaces of the step shaft.
4. Define the tolerances of deviation from roundness, radial palpitation and coaxiality of ***increased relative geometrical accuracy.*** Write them down in symbols.
5. Measure and write down the deviation from roundness, radial palpitation and coaxiality of all surfaces of the step shaft.
6. Define the usefulness of all sizes and the deviation from roundness, radial palpation and coaxiality of the step shaft**.**
7. Draw the drawing of part №2 (step sleeve with hole).
8. Measure and write down all necessary sizes of the step sleeve and roughness of the surfaces.
9. Write down the symbols of ***deviation from roundness***, symbols of ***radial palpation*** and ***coaxiality*** of all surfaces of the step sleeve.
10. Define the tolerances of deviation from roundness, radial palpation and coaxiality of the ***normal relative geometrical accuracy.*** Write them down in symbols.
11. Measure and write down the deviation from roundness, radial palpitation and coaxiality of all surfaces of the step sleeve.
12. Define the usefulness of all sizes and deviation from roundness, radial palpation and coaxiality of the step sleeve.
13. Draw the ***schemes of measurements*** and write down the names of equipment.

Laboratory work №10
“Drawing requirements”

The purpose of work:
1. To get acquainted with choosing fits.
2. To get acquainted with technical requirements and characteristics of fixing.
3. To get acquainted with the equipment and methods of inspection of the surface form and disposition, and measurements of sizes.
4. To estimate the accuracy of controlled parts and write down the accordance designations.

Basic rules on the theme of work

1. Requirements to the assembly drawing

Assembly drawings (fig. 1) are necessary for understanding the arrangement of parts in a mechanism or unit, the degree of mobility of mating parts, which is necessary for understanding its work. Fits of mating parts and their base sizes are specified in the assembly drawings.

Technical requirements to the assembly of a mechanism are specified in the right bottom corner above the stamp of the assembly drawing. Example: 1. Deviation from coaxiality of surface axes B and D no more than 0.05 mm; 2. Cover 12 to collect on the paint.

Technical characteristics can be specified on the assembly drawing, for example: The maximal frequency of rotation of the target shaft is 1000 R.P.M.

The nominal sizes and accuracy of manufacturing fastened elements are specified on the drawing, for example, a target end of the shaft or distance between holes for fastening of the mechanism.

2. Requirements to the design drawing

Design drawing (***work or executive drawing***) (fig. 2) is used for manufacturing a part, therefore, all necessary kinds and sections, all sizes and extreme allowable deviations of these sizes are specified on it. The ***deviations*** are defined in tables according to a base size and a tolerance zone. The ***tolerance zone*** of a size is nominated ***according to the fit*** in the assembly drawing. The deviations of rough sizes (11 - 14 grades of tolerance) are not supposed to be specified, but in the right bottom corner of the drawing above the stamp the accuracy and position of a tolerance zone is shown.

Example: ***1. H12, h12, ± IT12/2***.

It means, that all sizes concerning internal dimensions (for example, holes) are made on H12, if the deviations of the size in the drawing are not specified. All outside dimensions (for example, a diameter of shaft or length of key) are made on h12. If the size does not concern either to the outside or internal, it is made with a symmetric arrangement of the tolerance zone. The tolerance of the corresponding grade of tolerance (in our example 12 grade of tolerance) is divided half-and-half and this is maximum (+) and minimum (-) limit deviations (for example, for size 50 mm and technical requirements $\pm IT12/2$ it will be 50 ± 0.125 mm). ***Generally, 14 grade of tolerance is used***, but for accurate branches of industries (for example, for aircraft or war industry) 11 grade of tolerance is used.

Roughness of all surfaces is shown in the work drawing. For a many surfaces having an identical roughness, the roughness is shown in the right top corner of the drawing. This mark shows, that if roughness on a surface is not shown, it is equal to the roughness specified in the right top corner. Usually, roughness is shown for roughly processed surfaces (Ra ≤ 10 μm or Rz ≤ 40 μm). The mark of roughness in the brackets in the corner of the drawing reminds that there are also surfaces with a different roughness, which is shown in the drawing. The conformity between the accuracy of manufacturing and a possible allowable roughness is observed:

Ra = 6.3 ... 10 μm for ***11 - 14*** grades of tolerance, but can be Rz = 20 - 60 μm;

Ra = 2.5 μm for ***8-10*** grades of tolerance;

Ra = 1.25 μm for ***7*** grade of tolerance;

Ra = 0.8 μm for ***6*** grade of tolerance.

Roughness and accuracy may not correspond. For example: the surface of the shaft is interfaced with rubber cuff. A high accuracy is not required here (9 grade of tolerance is required), but the roughness should be small (Ra ≤ 0.32 μm, polishing) for reliable condensation and increase of service life.

Hardness of surfaces of a part is shown above the stamp. If the shaft has exact surfaces (6 - 7 grades of tolerance), one is usually quenched and then tempered and has the Rockwell hardness from 42 to 46 units (HRC_A = 42 – 46). Parts of other types are not usually quenched and have hardness HB = 180 - 260 depending on the mark of a material.

Other technical requirements also can be specified above the stamp. For example: 1) Center holes at the ends of the shaft are permissible. 2) Oxidizes. 3) To mark «M12» on a surface A. 4) Radii are 2.5 mm, etc.

Tolerances of the form and disposition of surfaces are shown by conventional signs on the contour of a part, but can be specified in technical requirements. For example: 1) The deviation from coaxiality of surfaces B and D is no more than 0.05 mm.

The scale is written in the stamp. For example, 1:2, or 5:1, etc.

Grade of a material (mark) is written in the stamp. For example, steel 45.

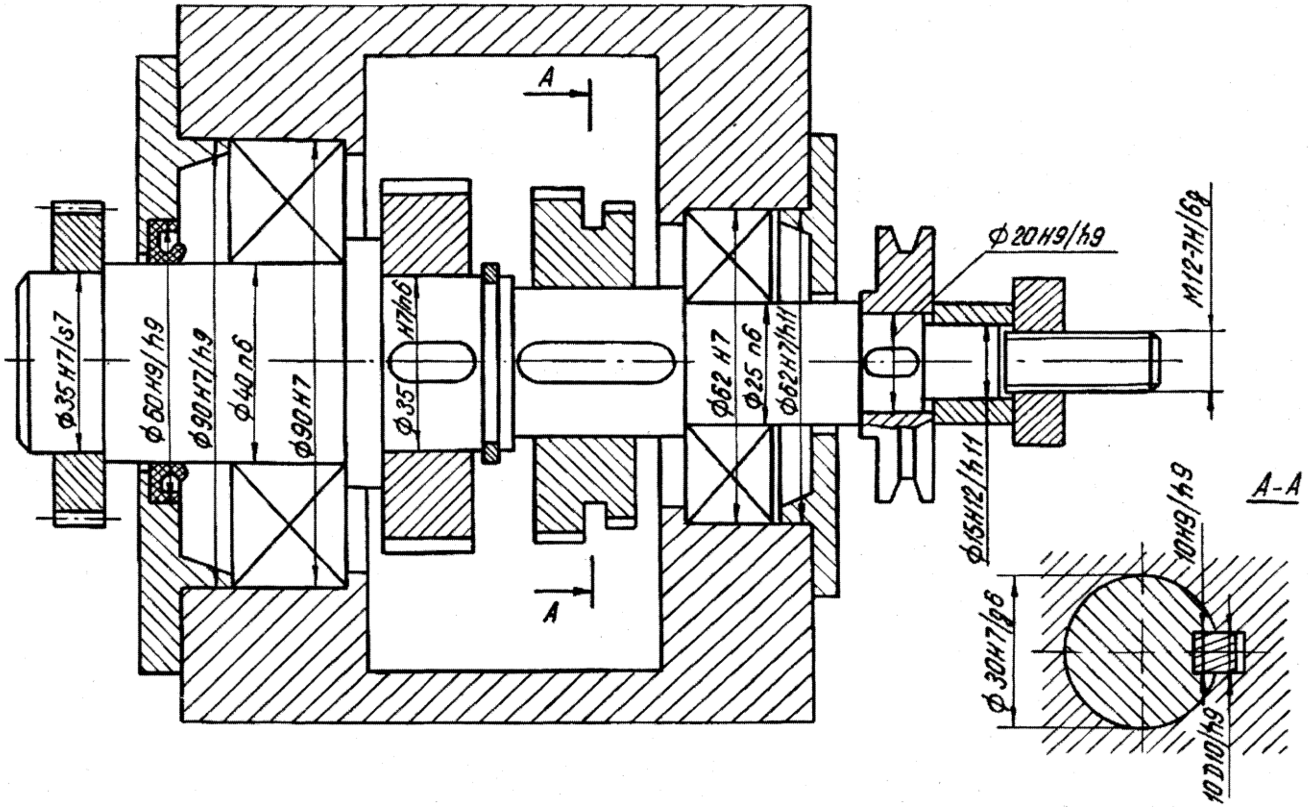
Weight of a part is written in the stamp. For example, 3.5 kg.

Executer is written in the stamp. For example, Vasiljeva T.A.

Controller is written in the stamp. For example, Kozlov V.N.

Name of a part is written in the stamp. For example, Shaft of reducer.

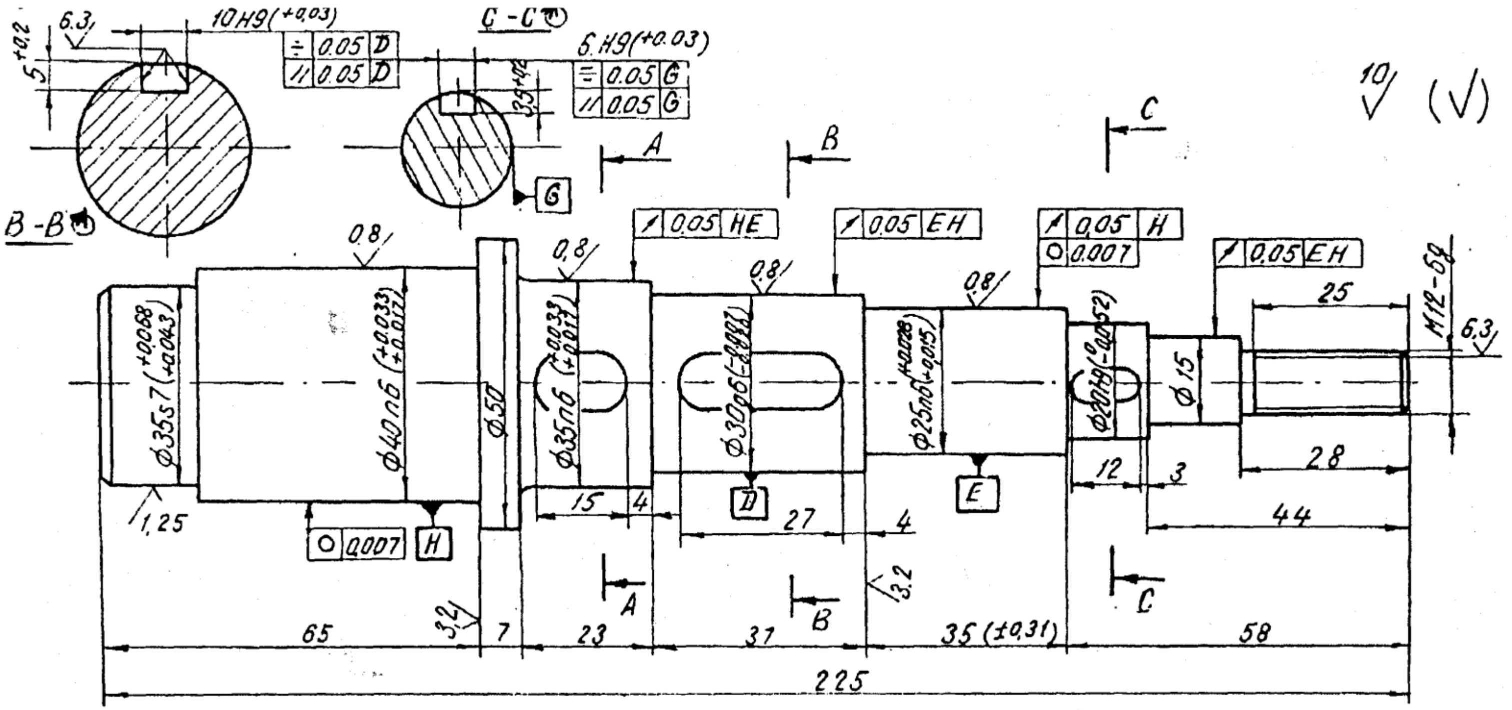
Designation of the product (part) is written in the stamp. For example, *TMECT. 1201. 14. 03*. (department of *Technology of Mechanical Engineering, Cutting and Tools*, speciality *1201 (technology of mechanical engineering),* number of assembly drawing *14 (*for example, mechanism of *reducer*), position of the part in specification *03 (*in our example *"Shaft of reducer").*

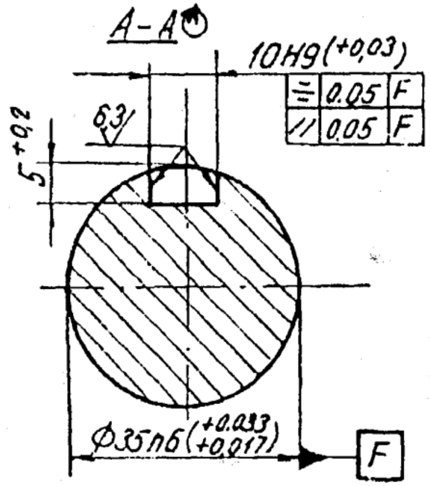


1. The maximal frequency of rotation of the target shaft is 1000 R.P.M.

					GC TMECT 552900.02			
Mes	Shit	№ dokum	Sign	Date	**Reducer №5**	Liter	Weight	Scale
Executed by		Vasilas G.		15.06.03				
Checked by		Kozlov V.		15.06.03				
T. contr.						Shit №1	Quantity of shits 1	
					Steel 40X	TPU, IIE, gr. 15TA90		
N. contr.								
Approved by.								

Fig. 1. An assembly drawing.





1. H14, h14, ±IT14/2.
2. $HRC_э$ 45…50.
3. Center holes at the ends of the shaft are permissible.

					GC TMECT 552900.02			
						Liter	Weight	Scale
Mes	Shit	№ dokum	Sign	Date	Shaft №3	p	3.5 kg	1:2
Executed by		Vasilas G.		15.06.03				
Checked by		Kozlov V.		15.06.03				
T. contr.						Shit № 1	Quantity of shits 1	
					Steel 40X	TPU, IIE, gr. 15TA90		
N. contr.								
Approved by.								

Fig. 2. A design drawing.

A division of the measuring tool has to be from 5 to 10 times less than the size tolerance of the measured part. For example, for $50_{-0.3}$ mm a division has to be 0.05…0.03. That is why we can use a virnier caliper (with a division of 0.05 mm) or a micrometer (with a division of 0.01 mm, a of range 25–50 mm).

Task:

1. Draw an assembly drawing and all views or cross sections. Write down all fits.
2. Draw an design drawing and all views or cross sections. Write down all deviations, roughness of surfaces, etc. (see ***Requirements to the design drawing***).
3. Draw all tolerance zones for all fits. Determine limit clearances or interferences.
4. Write down names of all measuring instruments required for inspection of size, deviation from the surface and disposition of surfaces, roughness of surfaces, hardness, etc.

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