International Standard 230/1

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Acceptance code for machine tools — Part 1 : Geometric accuracy of machines operating under no-load or finishing conditions

Code de réception des machines-outils — Partie 1 : Précision géométrique des machines fonctionnant à vide ou dans des conditions de finition

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 230/1 was prepared by Technical Committee ISO/TC 39, *Machine tools.*

It cancels and replaces ISO Recommendation R 230-1961, of which it constitutes a minor revision.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

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Acceptance code for machine tools — Part 1: Geometric accuracy of machines operating under no-load or finishing conditions

0 Introduction

The purpose of ISO 230 is to standardize methods of testing the accuracy of machine tools, excluding portable machine tools: it consists of the following parts:

Part 1: Geometric accuracy of machines operating under no-load or finishing conditions.

Part 2: Determination of accuracy and repeatabiity of positioning of numerically controlled machine tools.[1]

Part 3: Accuracy of machines operating under load.[2]

Part 4: Vibration.[2]

Part 5: Sound level.[1]

Part 6: Safety.[2]

1 Scope and field of application

The aim of this part of ISO 230 is to standardize methods of testing the geometric accuracy of machine tools, operating either under no-load or under finishing conditions, by means of geometrical and practical tests.

A *machine tool* is a power-driven machine, not portable by hand while working, which can be used for machining metal, wood, etc., by removal of chips or swarf or by plastic deformation.

This part of ISO 230 generally relates only to machines which cut metal by removing chips or swarf. In particular, special methods necessary for testing wood-working machines and machines which operate by plastic deformation are not included.

By *geometrical checks* is meant the checking of dimensions, forms and positions of components, as well as the checking of their displacement relative to one another. They comprise all the operations which affect the components of the machine (surface flatness, coincidence and intersection of axes, parallelism and perpendicularity of straight lines to straight lines, of flat surfaces to flat surfaces or of each to the other). They concern only sizes, forms positions and relative movements which may affect the accuracy of working of the machine.

By *practical test* is meant the machining of test pieces appropriate to the fundamental purposes for which the machine has been designed, and having predetermined limits and tolerances.

NOTE — This part of ISO 230 relates only to the checking of the accuracy itself. In particular, it deals neither with the checking of the running of the machine tool (vibrations, abnormal noises, stick-slip motion of components, etc., nor with the checking of characteristics (speeds, feeds), as these checks should normally be carried out before checking the accuracy of the machine tool.

After general considerations on definitions, test methods, use of checking instruments and tolerances, this part of ISO 230 deals more thoroughly with preliminary checking operations, practical tests and geometrical checks, and some special checks. An annex deals with the accuracy of instruments used for testing machine tools.

NOTE — This part of ISO 230 gives essentially a recommended selection of test methods by means of geometrical checks. Attention is drawn to the fact that, while geometrical checks are explained at length, the practical tests are not, as the problems of the inspection of components regarding position, dimensions and forms are properly dealt with in most technical books on metrology.

2 General considerations

2.1 Definitions relating to geometrical checks

A distinction should be made between geometrical definitions and those designated in this part of ISO 230 as metrological definitions.

Geometrical definitions are abstract and relate only to imaginary lines and surfaces. From this it follows that geometrical definitions sometimes cannot be applied in practice. They take no account of the realities of construction or the possibility of checking.

Metrological definitions are concrete, as they take account of real lines and surfaces accessible to measurement. They cover in a single result all micro- and macro-geometrical errors. They allow a result to be reached covering all causes of error, without distinguishing them from one another. The distinction should be left to the manufacturers.

1) At present at the stage of draft.

2) In preparation.

Nevertheless, in some cases, geometrical definitions (e.g. definitions of out-of-true running, periodic axial slip, etc.) have been retained in this part of ISO 230, in order to eliminate any confusion and to clarify the language used, but, when describing test methods, measuring instruments and tolerances, metrological definitions are taken as a basis.

2.2 Test methods and use of checking instruments

During the testing of a machine tool, if the methods of measurement only allow verification that the tolerances are not exceeded (e.g. limit gauges) or if the actual deviations could only be determined by high-precision measurements for which a great amount of time would be required, it is sufficient, instead of measuring, to ensure that the limits of the tolerance are not exceeded.

It should be emphasized that errors of measurement due to the instruments, as well as to the methods used, are to be taken into consideration during the tests. The measuring instrument should not give any error of measurement exceeding a given fraction of the tolerance to be verified. Since the accuracy of the devices used are very variable from one laboratory to another, a calibration sheet should be supplied with each instrument.

Test operations should be protected from draughts and from disturbing light or heat radiation (sunlight, electric lamps too close, etc.) and the temperature of the measuring instruments should be stabilized before measuring. The machine itself shall be suitably protected from the effects of external heat.

A given test should preferably be repeated, the result of the test being obtained by taking the average of the measurements. However, the various measurements should not show too great deviations from one another. If they do, the cause should be looked for either in the method or the checking instrument or the machine tool itself.

2.3 Tolerances

2.31 Tolerances on measurements when testing machine tools

Tolerances, which limit deviations to values which are not to be exceeded, relate to the sizes, forms, positions and movements which are essential to the accuracy of working and to the mounting of tools, important components and accessories.

There are also tolerances which apply only to test pieces.

2.311 Units of measurement, measuring ranges

When establishing tolerances, it is necessary to indicate:

a) the unit of measurement used;

b) the reference base and the value of the tolerance and its location to the reference base;

c) the range over which measurement is made.

The tolerance and the measuring range shall be expressed in the same unit system. Tolerances, particularly tolerances on sizes, shall be indicated only when it is impossible to define them by simple reference to International Standards for the components of the machine. Those relating to angles shall be expressed either in units of angle: degree, minute, second (one revolution = 360°), or as tangents (micrometres or millimetres per metre for countries using the metric system or inch per 10 in or inch per foot for countries using the inch-foot system).

When the tolerance is known for a given range, the tolerance for another range comparable to the first one shall be determined by means of the law of proportionality. For ranges greatly different from the reference range, the law of proportionality cannot be applied: tolerances shall be wider for small ranges and smaller for large ranges than those which would result from the application of this law.

2.312 Rules concerning tolerances

Tolerances include errors inherent in the measuring instruments and test methods used. Errors of measurement should consequently be included in the permitted tolerances (see 2.2).

Example:

Tolerance of run-out: X µm

Inaccuracy of instruments, errors of measurement: Y µm

Maximum permissible difference in the readings during the test $(X - Y)$ µm

Errors to be ignored are those of block gauges, reference discs, etc., inaccuracies arising from comparative laboratory measurements, inaccuracies of form of machine part used as reference surfaces, including surfaces masked by plungers or by support points of measuring instruments.

The actual deviation should be the arithmetical mean of several readings taken, ignoring the above causes of error.

Lines or surfaces chosen as *reference bases* should be directly related to the machine tool (e.g. line between centres of a lathe, spindle of a boring machine, slideways of a planing machine, etc.). The direction of the tolerance shall be defined according to the rules given in 2.325.

2.32 Subdivisions of tolerances

2.321 Tolerances applicable to test pieces and to fixed parts of machine tools

2.321.1 Tolerances of dimensions

The tolerances of dimensions indicated in this part of ISO 230 relate exclusively to the dimensions of test pieces for practical tests and to the fitting and to the fitting dimensions of cutting tools and of checking instruments which may be mounted on the machine tool (spindle taper, turret bores). They are the limits of permissible deviation from the nominal dimensions. They shall be expressed in length units (e.g. deviations of bearings and bore diameters, for the setting up and the centring of tools).

For internal and external dimensions of cylindrical and parallelepipedic parts, tolerances shall be given in compliance with the rules prepared by Technical Committee ISO/TC 10, *Technical drawings.* In particular, deviations should be indicated or the ISO symbols used.

Example:

$80 ^{+0,012}_{-0,007}$ or 80 j6

2.321.2 Tolerances of form

Tolerances of form limit the permissible deviations from the theoretical geometric form (e.g. deviations relative to a plane, to a straight line, to a revolving cylinder, to the profile of thread or of tooth). The shall be expressed in units of length or of angle. Because of the dimensions of the plunger surface or of the support surface, only part of the error of form is detected. Therefore where extreme accuracy is required, the area of the surface covered by the plunger or support shall be stated.

In a general way, the plunger surface should be proportional to the precision and to the dimension of the surface to be checked (a surface plate and the table of a heavy planing machine are not checked from the same plunger surface).

2.321.3 Tolerances of position

Tolerances of position limit the permissible deviations concerning the position of a component relative to a line, to a plane, or to another component of the machine (e.g. deviation of parallelism, of perpendicularity, of alignment, etc.). They shall be expressed in units of length or angle.

When a tolerance of position is defined by two measurements taken in two different planes, the tolerance should be fixed in each plane, when the deviations from those two planes do not affect the working accuracy of the machine tool in the same way.

NOTE — When a position is determined in relation to surfaces showing errors of form, these errors of form should be taken into account when fixing the tolerance of position.

2.321.4 Rules for the influence of defects of form in determining positional errors

When positional errors of two surfaces or of two lines (see figure 1, lines XY and ZT) are being determined, the readings of the measuring instrument automatically include some errors of form. It shall be laid down, as a principle, that checking shall apply only to the total error, including the errors of form of the two surfaces or of the two lines. Consequently, the tolerance shall take into account the tolerance of form of the surfaces involved. (If thought useful, preliminary checks may ascertain defects of form of lines and of surfaces, of which the relative positions are to be determined.)

When setting out on a graph (see figure 1) the different readings mn of the checking instrument, a curve, such as AB, is obtained. It is to be accepted, when there is no contradictory stipulation, that the error is to be determined by using, instead of this curve, a line calculated from the minimun squared deviation.

2.322 Tolerances applicable to the displacement of a component of a machine tool

2.322.1 Tolerances of dimensions

Tolerances of dimensions limit the permissible deviation of the position reached by a point on the moving part from that which it should have reached after moving.

Examples

1 Deviation *d*, at the end of the travel, of the position of a lathe cross slide from the position which it should have reached under the action of the lead screw (see figure 2).

2 Angle of rotation of a spindle relative to the angular displacement of a dividing plate coupled to it.

2.322.2 Tolerances of form

These limit the deviation of the actual trajectory of a point relative to the theoretical trajectory (see figure 3). They shall be stated in units of length.

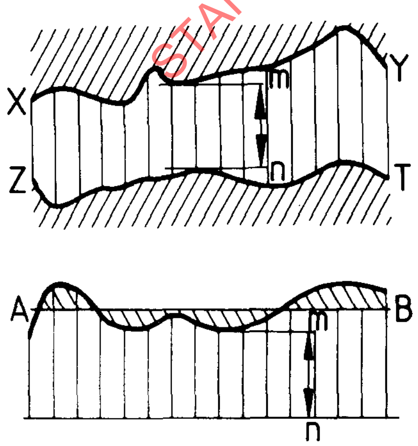


Figure 1

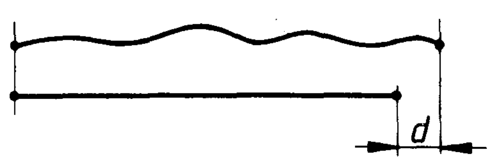


Figure 2

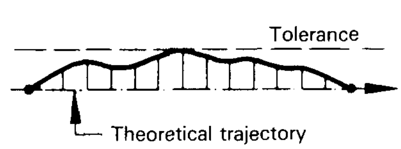


Figure 3

2.322.3 Tolerances of position

Tolerances of position limit the permissible deviation between the trajectory of a point on the moving part and the trajectory laid down (e.g. deviation of parallelism between the trajectory and a straight line or a surface) (see figure 4). They shall be expressed in units of angle or preferably as successive tangents over a given measurement of length.

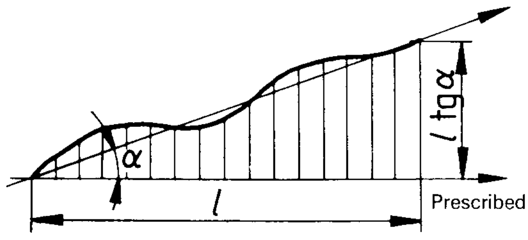


Figure 4

2.322.4 Local tolerances

Tolerances of form and position are usually relative to the form or position as a whole, e.g. 0,03/1 000 for a straightness or flatness. It should be observed that checking can show up a deviation (see figure 5) which is not spread over the whole of the form or position, but is concentrated on a short length of the former (e.g. 200 mm). If such defects, seldom met with in practice, are to be avoided, the overall tolerance may be accompanied by a statement of a local tolerance; or it may be simply agreed that the local tolerance, provided that it does not fall below a minimum to be stated (e.g. 0,01 or 0,005 mm) should be proportional to the overall tolerance. In the case under consideration, relating for example to straightness, the local error shall not in these conditions exceed:

$$\frac{0{,}03}{1\ 000} \times 200 = 0{,}006 \text{ mm}$$

If 0,01 mm is accepted as a minimum for any given machine, it is sufficient to check that the local error does not exceed this value.

In practice, local defects are generally imperceptible, as they are covered by the supporting or the feeling surfaces of the measuring instruments. However when the feeling surfaces are relatively small (plungers of dial gauges or micro-indicators), the measuring device should be such that the plungers follow a surface of high grade finish (straightedge, test mandrel, etc.).

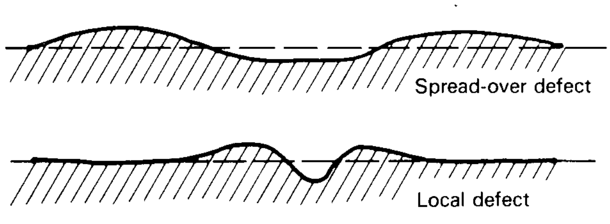


Figure 5

2.323 Cumulative or inclusive tolerances

The cumulative tolerances are the resultant of several deviations and may be determined by a single measurement, without it being necessary to know each deviation.

Example (see figure 6) : The tolerance for the run-out of a shaft is the sum of the tolerance of form (out-of-round of the circumference ab on which the plunger is in contact), the tolerance of position (the geometrical axis and the rotating axis of the shaft do not coincide) and the tolerance of out-of round of the bore of the bearing.

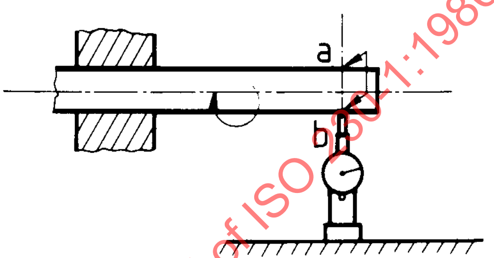


Figure 6

2.324 Symbols and positions of tolerances for relative angular positions of axes, slideways, etc.

When the position of the tolerance in relation to the nominal position is symmetrical, the sign ± may be used. If the position is asymmetrical it shall be stated precisely, in words,

— either in relation to the machine or to one of the components of the machine, or

— in relation to the operator in his conventional position.

2.325 Conventional position of the operator

For each type of machine a conventional position of the operator shall be defined. The *front* of a machine shall be the part which faces the operator. The *right* of a machine shall be the part which is at his right. The *rear* and the *left* of a machine shall be the parts respectively opposite to those already defined.

3 Preliminary checking operations

3.1 Installation of the machine before test

Before proceeding to test a machine tool, it is essential to fix the machine upon suitable foundations and to level it in accordance with the instructions of the manufacturer.

3.11 Levelling

The preliminary operation of installing the machine shall involve (see 3.1) precise levelling and is essentially determined by the particular machine concerned.

In the case of a lathe, the plane of the slides (front and rear) shall be laid horizontally or with a suitable slope. The cross slide shall be placed in the middle of the bed. When jacks and fixing bolts are used, the extreme ends of the slideways shall be placed horizontally and the twisting of the bed shall be remedied if necessary. For this purpose, the level shall be placed in succession (see figure 7) on the longitudinal positions a, b, c and d, and the transverse positions e and f.

After the first installation, checking of the straightness of the slideways (or straightness of the movement of the slide) may be made. It should be noted that this checking is not distinguishable from the setting out of the machine, particularly in the case of large-sized beds. Jacks are often spaced along the bed to effect local corrections as the checking of the slideways progresses.

When installing milling machines, the table of the machine shall be set approximately horizontal; the purpose of this is to facilitate the test operations.

Generally, it is desirable to follow the manufacturer's instructions for the proper setting-out of the machine and for the provision of suitable foundations which, in certain cases, are indispensable.

3.2 Condition of the machine before test

3.21 Dismantling of certain components

As the tests are carried out, in principle, on a completely finished machine, dismantling of certain components should only be carried out in exceptional circumstances, in accordance with the instructions of the manufacturer (e.g. dismantling of a grinding machine table in order to check the slideways).

3.22 Temperature conditions of certain components before test

The aim is to check the accuracy of the machine under conditions as near as possible to those of normal functioning as regards lubrication and warming up. During the geometrical and practical tests, components, e.g. spindles, which are liable to warm up and consequently to change position or shape, shall be brought to the correct temperature by running the machine idle in accordance with the conditions of use and the instructions of the manufacturer.

3.23 Functioning and loading

Geometrical checks shall be made either when the machine is at a standstill or when it is running idle. When the manufacturer specifies it, for example, as in the case of heavy-duty machines, the machine shall be loaded with one or more test pieces.

4 Practical tests

4.1 Testing

Practical tests shall be carried out on pieces the making of which does not require operations other than those for which the machine has been built. Practical tests to ascertain the precision of a machine tool shall be the finishing operations for which the machine has been designed. (It is of primary importance that such tests should be carried out in good faith.)

The number of workpieces or, as the case may be, the number of cuts to be made on a given workpiece, shall be such as to make it possible to determine the average precision of working. If necessary, wear on the cutting tool used should be taken into account.

The nature of the workpieces to be made, their dimensions, their material and the degree of accuracy to be obtained and the cutting conditions shall be settled by agreement between the manufacturer and the user, unless ISO specifications already exist.

4.2 Checking of workpieces in practical tests

Checking of workpieces in practical tests shall be done by measuring instruments selected for the kind of measurement to be made and the degree of accuracy required.

The tolerances indicated in 2.321, particularly in 2.321.1 and 2.321.2, are to be used for these checks.

4.3 Importance of practical tests

The results of practical tests and geometrical checks can be compared only insofar as these two kinds of tests have the same object. There are cases moreover when, on account of expense or technical difficulties in conducting the tests, the accuracy of a machine is checked only by geometrical checks or only by practical tests.

If the tests by means of geometrical checks and practical tests having the same object do not give the same results, those results obtained by making practical tests should be accepted as the only valid ones.

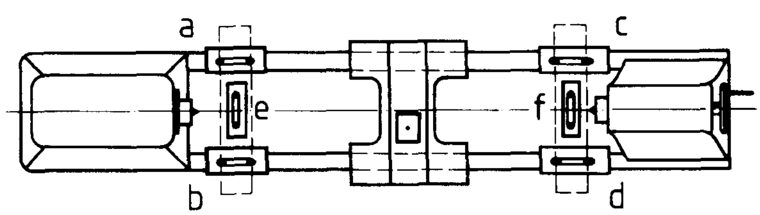


Figure 7

5 Geometrical checks

5.1 General

For each geometrical check of a given characteristic of shape, position or displacement of lines or surfaces of the machine:

- straightness (see 5.2),
- flatness (see 5.3),
- parallelism, equidistance and coincidence (see 5.4),
- squareness (see 5.5),
- rotation (see 5.6),

a definition[1], a method of measurement and the way of determining the tolerance are given.

For each test, at least one method of measurement has been indicated, and only the principles and apparatus used have been shown.

When other methods of measurement are used, their accuracy shall be at least equal to the accuracy of those in this part of ISO 230.

Although, for the sake of simplicity, the methods of measurement have been chosen systematically from those which employ only the elementary test instruments most frequently used in engineering workshops, such as straightedges, squares, mandrels, measuring cylinders, spirit levels and dial gauges, it should be observed that other methods, notably those using optical devices, are in fact generally used in machine tool building and in inspection departments. Testing of machine tool parts of large dimensions often requires the use of special devices for convenience and speed.

5.2 Straightness

Geometrical checks covering straightness are the following:

- straightness of a line in two planes, see 5.21;
- straightness of components, see 5.22;
- straight line motion, see 5.23.

5.21 Straightness of a line in two planes

5.211 Definition

A line is deemed to be straight over a given length when the variation of the distance of its points from two planes perpendicular to each other and parallel to the general direction of the line remains below a given value for each plane.

Reference planes shall be chosen so that their intersection is parallel to the straight line joining two points suitably located on the line to be tested. The two points should be close to the ends of the length to be measured.

1) See also 2.1.

5.212 Methods of measurement

It is recommended to use:

a) for lengths below 1 600 mm or 63 in:

a spirit level or straightedge conforming to International or national Standards, as the case may be,

b) for lengths above 1 600 mm or 63 in:

the methods of measurement by means of a spirit-level, or of optical devices (the autocollimation method, the microscope and taut wire).

5.212.1 Straightedge method

The straightedge should be placed on two blocks, located, if possible, at the points corresponding to the minimum deflection.

The measurement shall be made by moving along the straightedge a rider of which one point rests on the surface to be measured and the other carries a dial gauge, the plunger of which is in contact with the straightedge (see figure 8).

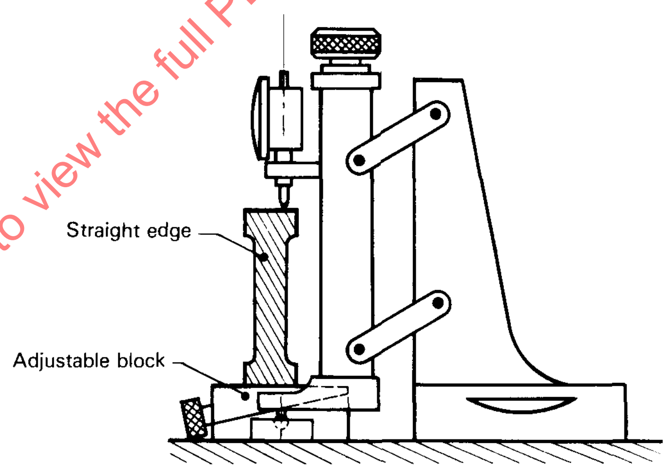


Figure 8

The straightedge is set to give identical readings at both ends of the line (e.g. by means of adjustable blocks); errors in the line AMB relative to the straight line AB joining the two extremes may be read off directly [see figure 9a)].

The straightedge may also be set without aiming at identical readings at both ends of the line; the readings are then plotted graphically and the errors checked in relation to the straight line AB [see figure 9b)].

5.212.2 Spirit-level method or autocollimation method

In the spirit-level method, the reference plane is the horizontal plane, as defined by the level.

In the autocollimation method, the reference line is a light beam.

Measurements shall be taken at successive equidistant points. These shall then be set out on a chart of the angles and the general direction XY in relation to the line AB checked (see figure 10).

Deviations MN perpendicular to this line shall not exceed the specified tolerance.

5.212.21 Spirit-level method

1) The line is reasonably horizontal

The initial straight line of reference is constituted by the straight line omx, o and m being two points on the line to be checked (see figure 11).

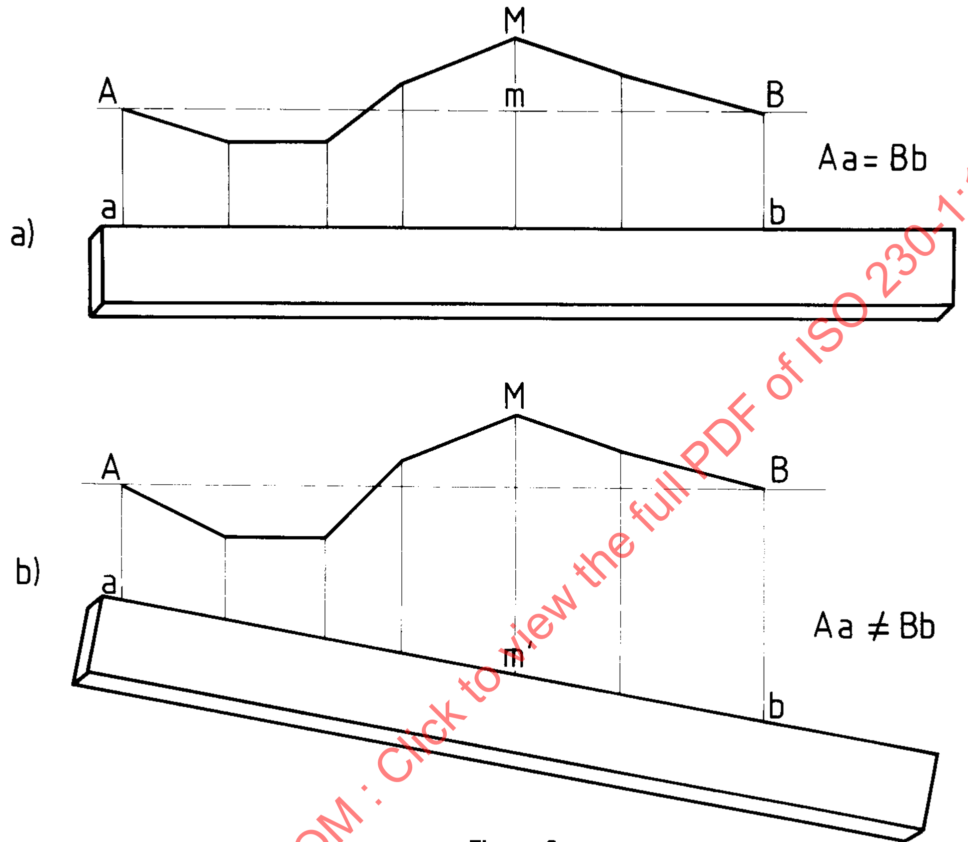


Figure 9

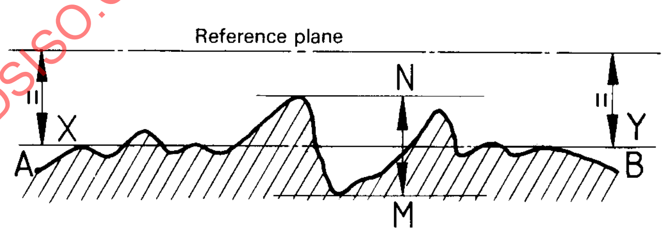


Figure 10

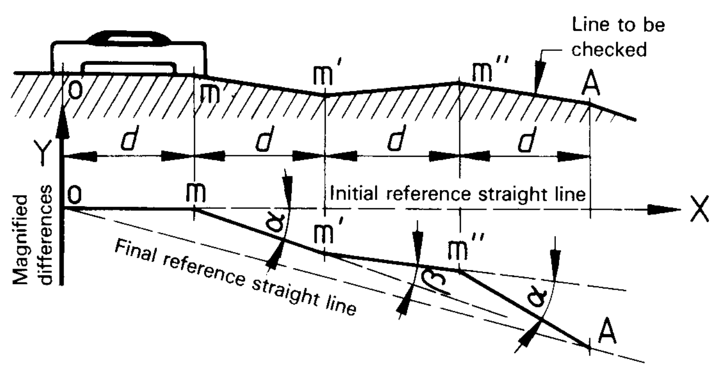


Figure 11

The level is placed on om, then moved to mm', then to m'm'', the distances om, mm', being all equal to a value d, related to the total length oA, which is to be checked (d in practice lies between 100 and 500 mm).

Readings of the level on mm', m'm'' are compared with the reading of the level in its original position om. If the level is provided with a regulating device for the bubble, the bubble should be brought to zero in the original position so as to obtain in the operations which follow a direct reading of the positions of the lines mm', m'm'', in relation to omX. When the distance oA has been traversed, measurements are taken in the opposite direction Ao using the same points, and the average of the results obtained is calculated. All the information needed to trace the profile of the line omm'm''A is then available.

To eliminate local errors in the course of measurement, the level should not be laid on the lines to be tested over the full length of its base. The base should be hollowed out in its central part, or, if this is not possible, the level should be placed on two gauge blocks of equal thickness or on a support with two feet separated by the distance d.

The feet of the level, or its support as the case may be, and the surfaces on which the device is to rest in the course of the test, shall be very carefully cleaned.

2) The line is not horizonal

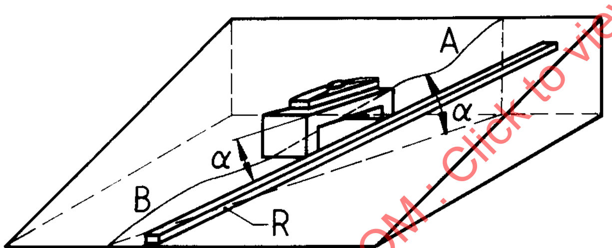
When a line is inclined, the procedure of the last example may be applied, if a support having an angle α equal to the angle of inclination in relation to the horizontal plane is used (see figure 12).

NOTE — The level permits checking the straightness only in the vertical plane; to check a line in a second plane, another method should be used (e.g. taut wire and microscope).

5.212.22 Optical checks

Numerous methods using optical devices may be used to verify the straightness of a line. The most general are the autocollimation method (measuring the slope) and the method using an alignment telescope (measuring the difference in level).

1) In the autocollimation method, using a telescope and a microscope mounted coaxially (see figure 13), any rotation of the movable mirror M around a horizontal axis entails a vertical displacement of the image of the reticle in the focal plane; the measurement of this displacement, which may be made with an ocular micrometer, permits the angular deviation α of the mirror holder to be determined.



While checking line AB, the level together with is support should keep a constant orientation (e.g. by means of a guiding straightedge R)

Figure 12

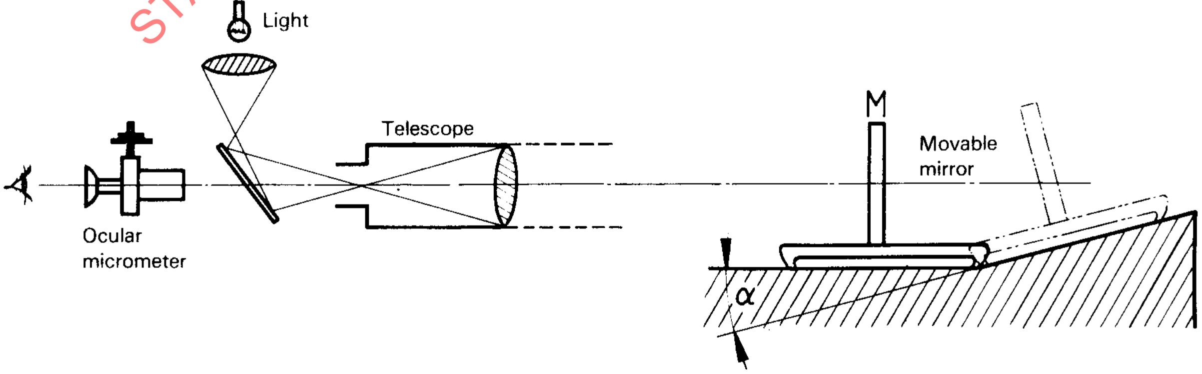


Figure 13

2) In the method using an alignment telescope (see figure 14), the measurement of the difference in level a[1], corresponding to the distance between the optical axis of the telescope and the mark shown on the target, is read directly on the reticle or by means of the optical micrometer.

5.212.3 Checking by means of the taut wire and microscope

A steel wire, with a diameter of about 0,1 mm, is stretched to be approximately parallel to the line to be checked (see figure 15). For example, in the case of a line MN, located in a horizontal plane, with a microscope placed vertically and equipped with a horizontal micrometric displacement device, it is possible to read the deviation of the line to the taut wire in the horizontal plane of measurement XY.

The taut-wire method is to be avoided when the sag of the wire has to be taken into account. Thus, in the case of figure 15 with a microscope placed horizontally, it is possible to measure the straightness of line RS in a vertical plane when the sag f of the wire is known at each point, but this sag is extremely difficult to determine with adequate accuracy.

5.213 Tolerance

The tolerance of the straightness of a line is the maximum permissible deviation in relation to the reference straight line joining the two extremities of the line to be checked (see figure 10, line XY).

The range of measurement, i.e. the length to be checked, and, possibly, the position of the tolerance in relation to the reference straight line (or plane) defined above, should be stated.

In most cases, parts very close to the ends, which most often have local errors of no great importance, may be ignored.

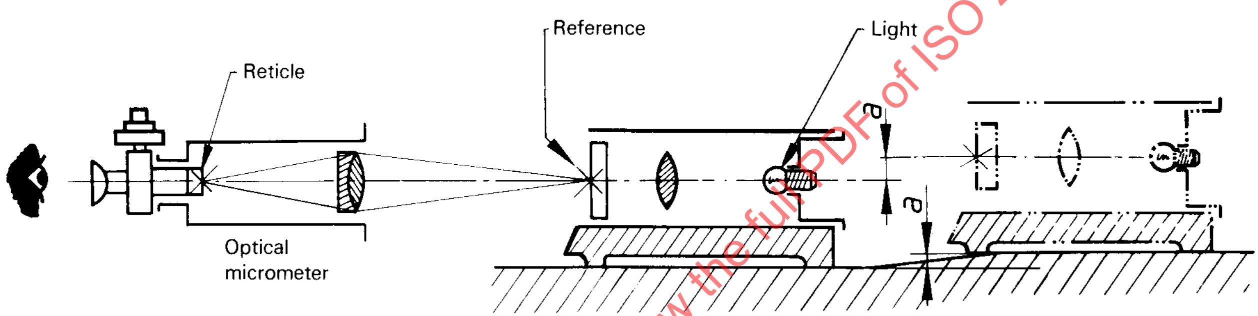


Figure 14

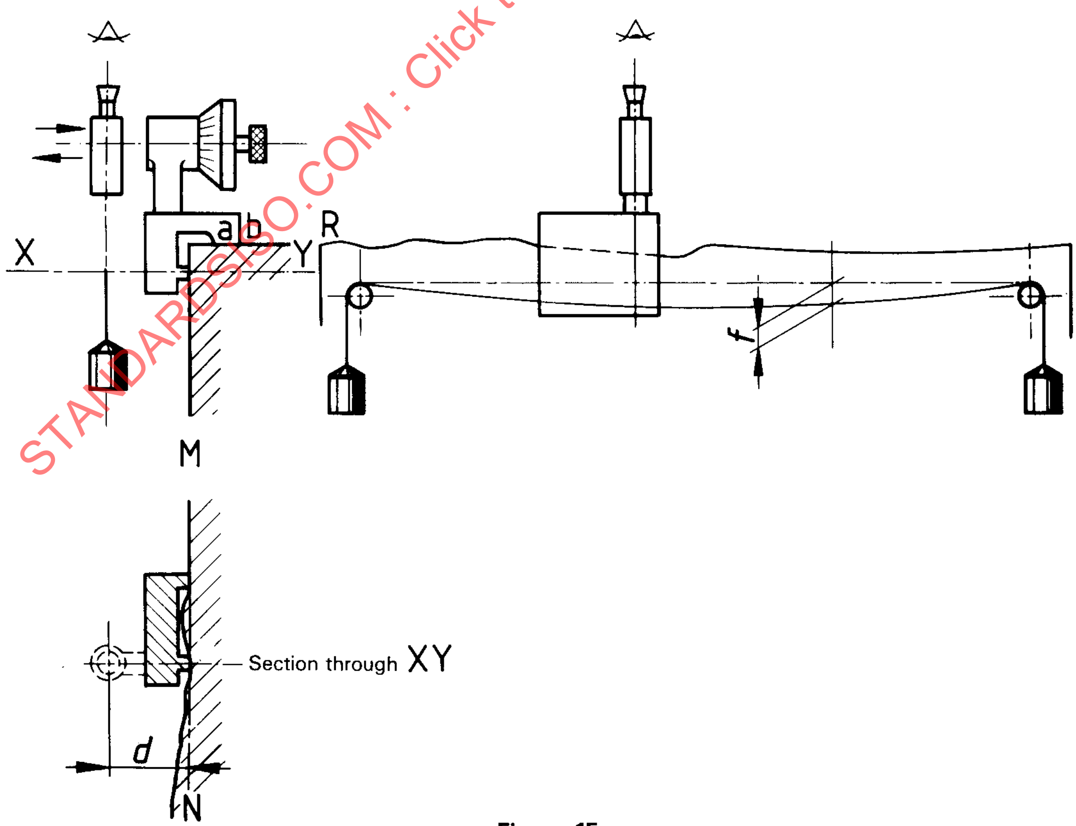


Figure 15

1) i.e. of the deviation a in the measuring plane, whether it is a vertical or a horizontal plane.

5.22 Straightness of components

5.221 Definition

The conditions for the straightness of a component are the same as those for a line (see 5.211).

This clause relates particularly to slideways of machine tools.

5.222 Methods of measurement

The methods indicated in 5.212.1 to 5.212.3 are applicable for plane slideways.

For V slideways, the level is laid on a cylinder or an intermediate piece made to the shape of the slideways (see figure 16).

A traverse, such as shown in (2) in figure 17, may also be used. It allows:

a) checking of the slideways lengthwise,

- either with the level for straightness in a vertical plane (support faces (A) and (B)),
- or the taut wire (3) and microscope (1) for straightness in a horizontal plane,

b) checking of the slideways crosswise with the level (support (B) and (C)).

5.223 Tolerances

The tolerances are identical with those defined in 5.213.

5.23 Straight line motion

5.231 Definitions

In the *straight line motion* of a component, the trajectory of a point on that component is parallel to a reference line parallel to the general direction of the motion.

The expression accuracy of straight line motion refers to the trajectory of a point on a component of the machine when effecting a working or setting motion. Checking of straight line motion is preferable to checking for straightness of slideways or beds, since it is the only method which takes into account all factors likely to affect the motion.

There are several kinds of straight line motion, i.e.:

- *of an axis on itself:* when this axis remains within the two right-angled planes which contain it at rest;
- *of a plane surface in its own plane:* when this surface remains in its own plane;
- *of a component parallel to a straight line or a surface:* when any point on this component remains at an equal distance from the line (or from the surface);
- *of a component perpendicular to a given plane:* when each point of the component describes a trajectory perpendicular to the given plane (see 5.512.4, an axis and a plane at 90° to each other).

5.232 Methods of measurement

The tests for straight line motion are in effect tests for parallelism or perpendicularity identical with those described in the clauses on those tests.

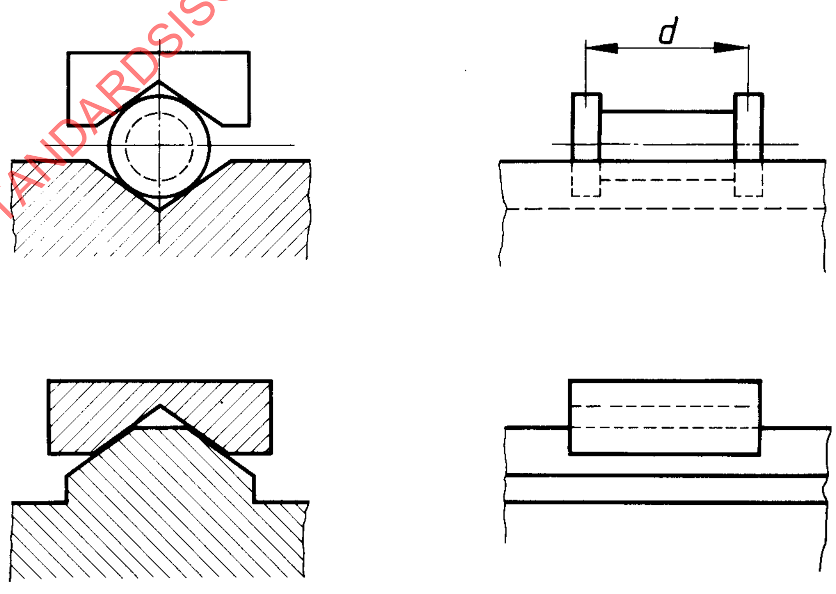


Figure 16

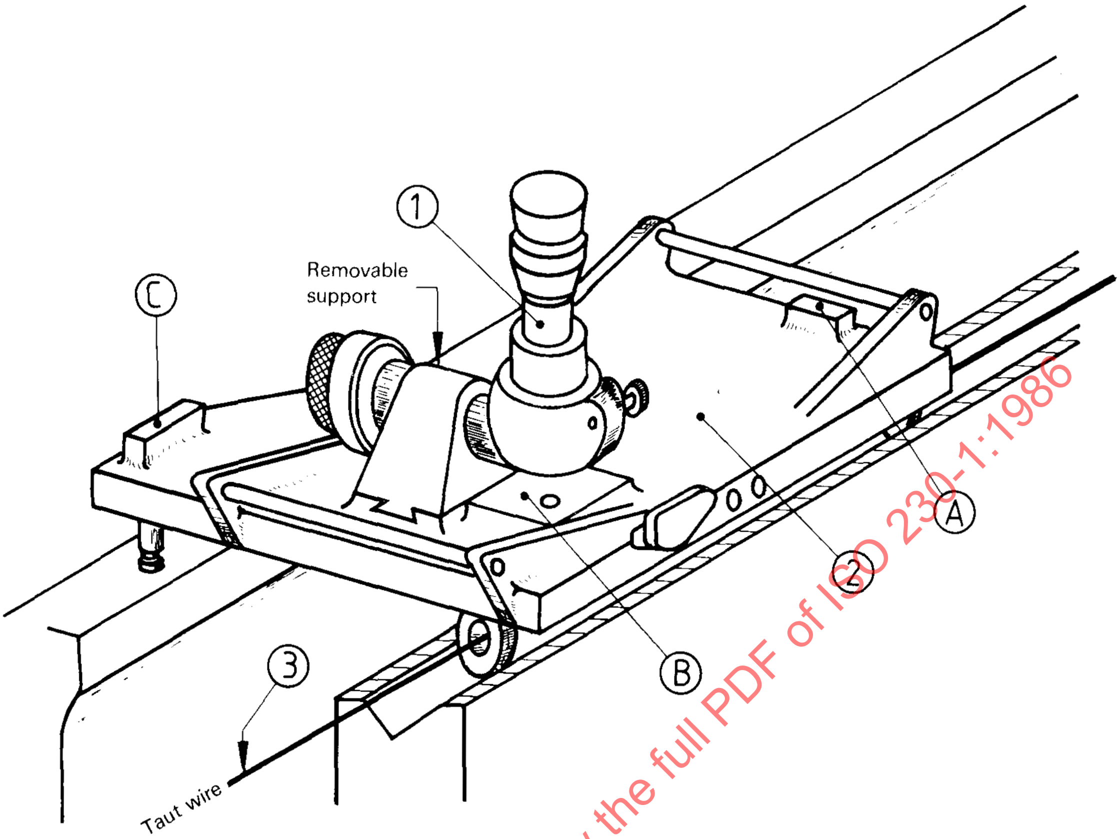


Figure 17

5.232.1 Checking with a straightedge and a dial gauge

A dial gauge should be fixed to the moving component of the machine, the plunger sliding along the straightedge representing the reference line (see figure 18).

When the moving component is a tool holder, the dial gauge should as nearly as possible be mounted so that the plunger is in a position where, in normal working, the tool is in contact with the workpiece. In this way, allowance can be made for the actual amount of secondary movement of the moving components, e.g. stick-slip, weave, interrupted movement, etc. For the same reason, the moving component shall be driven in the same way as when the machine is working normally (see also 5.212.1).

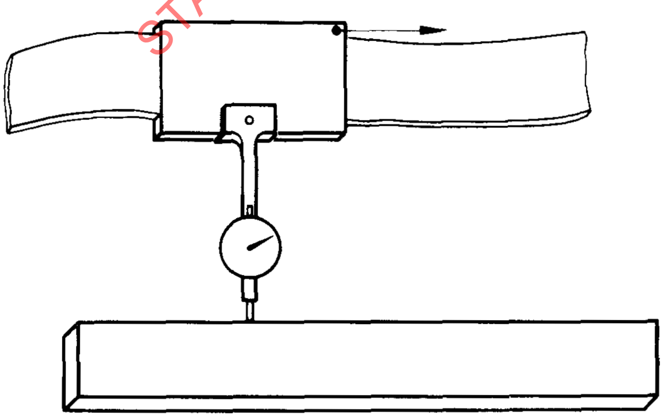


Figure 18

5.232.2 Checking with microscope and taut wire

When the travel is long, the reference line may be represented by a tightly stretched thin steel wire. The dial gauge is replaced by a microscope. Deviations are read directly from the scale of the eyepiece (see 5.212.3).

5.232.3 Checking the straightness of a lathe slide displacement

(This checking is in fact effected only in the horizontal plane.)

a) Displacements not exceeding 1 600 mm (63 in)

A ground-measuring cylinder mounted between centres shall be used.

A dial gauge is mounted on the saddle in the place of the tool and the plunger brought into contact with the surface of the mandrel. The mandrel should be brought into position by adjusting the tailstock so that the dial gauge indications are equal at the two ends.

A first reading shall be taken along this surface; the mandrel is then rotated through 180° and a second reading taken. The cylinder shall then be turned end for end and the above two tests repeated. The mean of the four readings will eliminate possible errors due to errors in the cylinder.

b) Displacement over 1 600 mm (63 in)

The method of the taut wire and microscope should be used (see 5.212.3): the wire is stretched between centres, the operator sights the wire through a microscope on the cross slide; sights may be taken for various positions of the saddle on its slideways.

5.233 Tolerance

The tolerance for accurate straight line motion is the maximum permissible deviation, in relation to a straight line, of the trajectory of a point on the moving component.

The deviation in the plane indicated may be in either of two directions and may be distributed at random along the travel. If, for any reason, deviation is permissible in one direction only, this shall be specified, e.g. "Trajectory convex only in the vertical plane".

5.3 Flatness

5.31 Definition

A surface is deemed to be flat within a given range of measurement when the variation of the perpendicular distance of its points from a geometrical plane[1] parallel to the general trajectory of the plane to be tested remains below a given value. The geometrical plane may be represented either by means of a surface plate or by means of a family of straight lines obtained by the displacement of a straightedge, or by means of a spirit level or a light beam.

5.32 Methods of measurement

5.321 Checking of flatness by means of a surface plate

In measurement by means of a surface plate, the plate is covered by jeweller's rouge or by chromium oxide diluted in light oil. The surface plate covered in this way is laid upon the surface to be measured. A slight to and fro motion is applied. The plate is removed and the distribution of the contact points per surface unit is noted. This distribution should be uniform over the whole area of the surface and should be equal to a given value. The method is only applied for the smaller-sized surfaces which present a relatively fine finish (scraped or ground surfaces).

5.322 Checking of flatness by means of a family of straight lines by displacement of a straightedge

The theoretical plane on which the reference points will be located is first determined. For this purpose, 3 points, a, b and c on the surface to be tested are selected as zero marks (see figure 19). Three gauge blocks of equal thickness are then placed on these three points, so that the upper surfaces of the blocks define the reference plane to which the surface is compared. A fourth point d lying in the reference plane is then selected in the following manner, using gauge blocks which are adjustable for height; a straightedge is placed on a and c and an adjustable block is set at a point e on the surface and brought into contact with the lower surface of the straightedge. The upper surfaces of the blocks a, b, c, e, are therefore all in the same plane. The location of point d is then found by placing the straightedge on b and e; an adjustable block is placed at this point and its upper faces brought into the plane defined by the upper surfaces of the blocks already in position. By placing the straightedge on a and d and then on b and c, the locations of all the intermediate points on the surface lying between a and d and between b and c may be found. The locations of the points lying between a and b, c and d, may be found in the same way. (Any necessary allowance for sag in the straightedge should be made.)

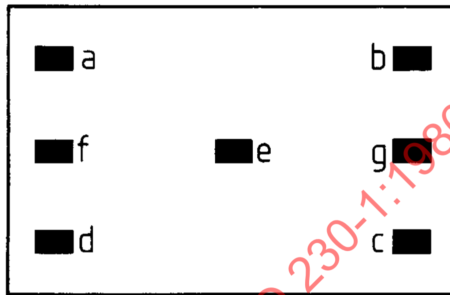


Figure 19

To obtain readings inside the rectangle or square thus defined, it will only be necessary to place at points f and g, for example, the locations of which will then be known, gauge blocks adjusted to the correct height. The straightedge is placed on these and, with the aid of the gauge blocks, the deviation between the surface to be tested and the straightedge can be measured. It is possible to use an instrument for the testing of straightness as shown, for example, in figure 8.

5.323 Checking of flatness by means of a spirit-level

The reference plane is determined by two straight lines omX and oo'Y, o, m and o' being three points of the surface to be checked (see figure 20).

The lines oX and oY are chosen preferably at right angles and if possible parallel to the sides outlining the surface to be checked. Checking is begun in one of the angles o of the surface and in the direction oX. The profile for each line oA and oC is determined by the method indicated in 5.212.21. The profile of longitudinal lines o'A', o''A'', and CB is determined so as to cover the whole surface.

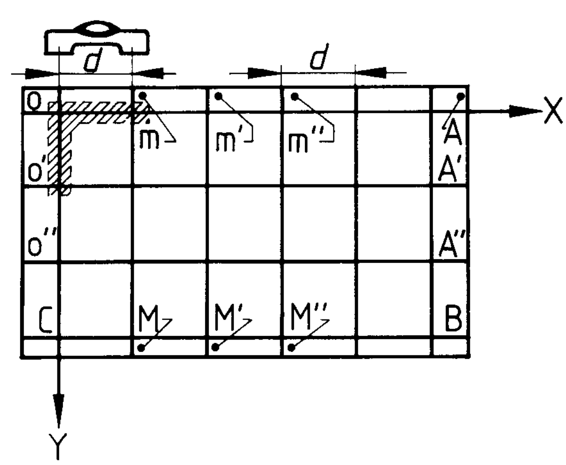


Figure 20

1) This plane should be exterior to the surface to be tested.

Supplementary checks may be made following mM, m'M', etc., to check the previous measurements.

When the width of the surface to be checked is not disproportionate to its length, it is desirable, as a cross-check, also to take measurements along diagonals.

5.324 Checking of flatness by optical methods

Straight lines oX and oY defining the reference plane are determined by the optical axis of the telescope in two positions and, if possible, at 90° to each other. The method given in 5.212.22 is then followed.

5.33 Tolerances

Flatness deviations are indicated as follows:

— error of flatness: ... µm or mm per m (... in per ft) when convexities are allowed as well as concavities;

— concave to... µm or mm when, between the ends, only concave surfaces are allowed;

— convex to... µm or mm when, between the ends, only convex surfaces are allowed.

The tolerances may not be identical in all directions. Checking is generally done longitudinally and transversely for each direction. The applicable tolerance shall be given in each case.

The results of the check are mainly determined by the surface of the plunger; it is often necessary to provide an additional indication, for instance:

plunger: 30 mm × 200 mm moving in the direction of its length, or
flat-end plunger ϕ 50 mm, or
spherical-end plunger ϕ 20 mm.

Under certain conditions of work, limits or extremities (ends) shall also be fixed for the plane to be checked.

5.4 Parallelism, equidistance and coincidence

The checks comprise the following points:

— parallelism of lines and planes, see 5.41;

— parallelism of motion, see 5.42;

— equidistance, see 5.43;

— coincidence or alignment, see 5.44.

5.41 Parallelism of lines and planes

5.411 Definitions

A line is deemed to be parallel to a plane if, when measuring the distance of this line from the plane at a number of points, the maximum difference observed within a given range does not exceed a predetermined value.

Two lines are deemed to be parallel when one of these lines is parallel to the two planes passing through the other line. The acceptable deviations are not necessarily identical in the two planes.

Two planes are deemed to be parallel when their distance from each other is measured anywhere on the surface and at least in two directions, and the maximum error over a specified length does not exceed an agreed value.

Maximum error means the difference between the maximum and the minimum dimensions obtained when measuring.

These differences are measured in given planes (horizontal, vertical, perpendicular to the examined surface, crossing the examined axes, etc.) within a given length (e.g. "on 300 mm", or "over the whole surface").

5.412 Methods of measurement

5.412.1 General, for axes

Where checking of parallelism involves axes, the axes themselves shall be represented by cylindrical surfaces of high precision of form, suitable surface finish and sufficient length. If the surface of the spindle does not fulfil these conditions, or if it is an internal surface and will not admit a feeler, an auxiliary cylindrical surface — test mandrel — is used.

Fixing and centring of the test mandrel shall be done on the end of the shaft or in the cylindrical or conical bore designed to take the tool or other fitments.

When inserting a test mandrel on the spindle axis so as to represent an axis of rotation, allowance shall be made for the fact that it is impossible to centre the mandrel exactly on the axis of rotation. When the spindle is rotating, the axis of the mandrel describes a hyperboloid (or a conical surface, if the axis of the mandrel intersects the axis of rotation) and gives two positions B-B' lying in the plane of test (see figure 21).

The checking of parallelism may, under these conditions, be effected in any position of the spindle, but should be repeated after rotating the spindle through 180°. The algebraic mean of the two readings gives the error of parallelism in the given plane.

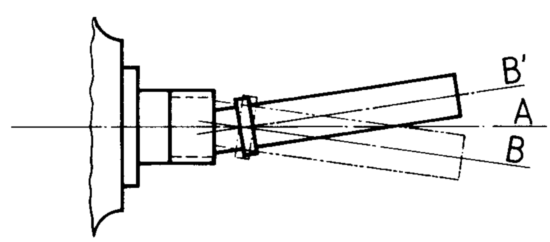


Figure 21

The mandrel may also be brought into the mean position A (named "mean position of run-out"); the checking should then be effected in this position only.

The first method seems to be as quick as the second, as well as more accurate.

NOTE — The term "mean position of run-out" is to be understood as follows: a gauge plunger is brought into contact, in the plane of tests, with the cylindrical surface representing the axis of rotation. The reading of the measuring instrument is observed as the spindle is slowly rotated. The spindle is in the mean position of run-out, when the pointer gives a mean reading between the two ends of its stroke.

5.412.2 Parallelism of two planes

The measuring instrument is held on a support with a flat base and moved in one of the planes by the amount specified. The plunger slides along the second plane (see figure 22).

This test shall be carried out in two directions preferably perpendicular to each other.

5.412.3 Parallelism of two axes

The test is made in two planes:

in a plane passing through the two axes[1],
then in a second plane perpendicular, if possible, to the first one.

5.412.31 Plane passing through the two axes[1]

The measuring instrument is held on a support with a base of suitable shape, so that it slides along a cylinder representing one of the two axes; the plunger slides along the cylinder representing the second axis.

To determine the minimum deviation between the axes at any point, the instrument shall be gently rocked in a direction perpendicular to the axes (see figure 23). If necessary, the deflection of the cylinder under the weight it will have to support during the tests may be taken into consideration.

5.412.32 Second plane perpendicular to the first

This check needs an additional plane, if possible parallel to the one passing through the two axes.

If this additional plane exists, by virtue of the fact that the two axes are parallel to a surface of the machine, the parallelism of each axis, considered separately, shall be determined in relation to this surface in the manner described in 5.412.4. If not, the test should be made with reference to a theoretical plane by means of a level with an adjustable glass tube. For this purpose, the latter should be placed on the two cylinders representing the axes, and the air-bubble set to 0. If the two axes are not in the same horizontal plane, an auxiliary block (see figure 24) may be used for slight angles of inclination, and, for greater angles, a fixed or adjustable square (see figure 25).

The level is moved along the axes by the amount specified, and readings taken. The measurement is expressed in terms of the distance between the axes. If, for example, this distance is 300 mm (12 in) and the level reading is 60 µm/m (0.002 16 in per 3 ft), the error of parallelism will be $60 \times 0{,}3 = 18$ µm (0.000 72 in).

5.412.4 Parallelism of an axis to a plane

The measuring instrument is held on a support with a flat base and moved along the plane by the specified amount. The plunger will slide along the cylinder representing the axis (see figure 26).

At each point of measurement, the shortest distance is found by slightly moving the testing instrument in a direction perpendicular to the axis.

In the case of a pivoting axis, a test in the mean position and the two extreme positions will be sufficient (see figure 27).

5.412.5 Parallelism of an axis to the intersection of two planes

The measuring instrument is held on a support with a base of suitable shape resting on the two planes. The instrument is then moved the specified distance along the straight line of intersection, and the plunger will slide along the cylinder representing the axis (see figure 28). The check shall, as far as possible, be made in two perpendicular planes chosen as being of greatest importance in the operation of the machine tool.

5.412.6 Parallelism of the intersection of two planes parallel to a third plane

This check shall be made as in 5.412.5, the plunger of the measuring instrument sliding along the third plane. The plane of measurement is determined by setting the contact point at right-angles to the plane (see figure 29).

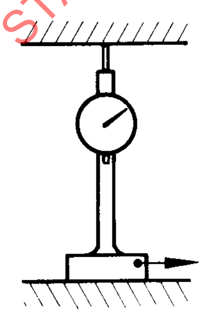


Figure 22

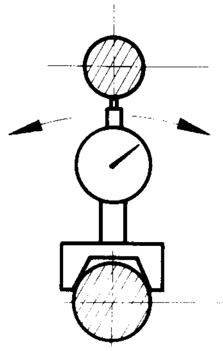


Figure 23

1) This expression here means a plane passing through one of the two axes and as near as possible to the second axis.

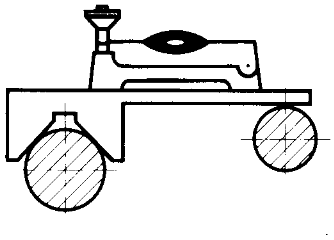


Figure 24

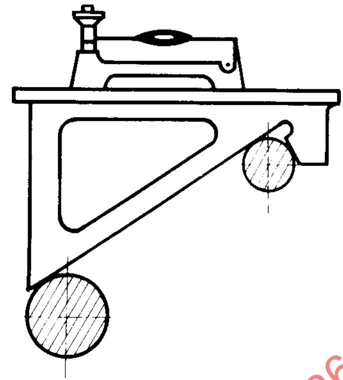


Figure 25

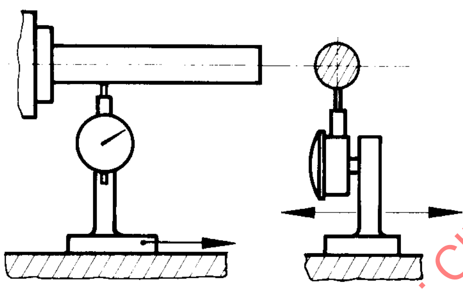


Figure 26

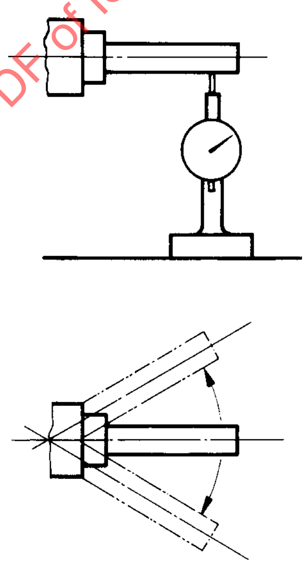


Figure 27

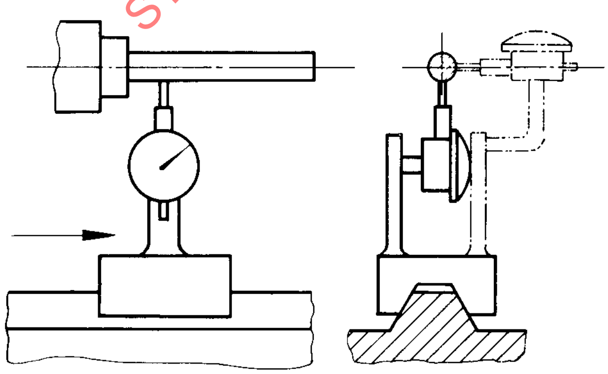


Figure 28

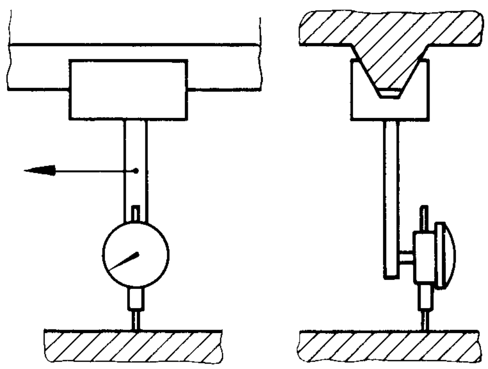


Figure 29

5.412.7 Parallelism between two straight lines, each formed by the intersection of two planes

This check may be carried out as in 5.412.5. The plunger of the measuring instrument bears on a V-block which will slide along the planes forming the second intersection. The check shall be made in two planes perpendicular to one another (see figure 30).

This method requires very rigid mounting of the measuring instrument, a condition which can be observed only in the case of two straight lines close to each other. As a rule, a level should be used, at least for the checking of parallelism in a vertical plane (see figure 31).

NOTE — If a direct check of the planes or straight lines concerned is difficult because of interference by components of the machine tool with the field of measurement, the check may be related to a reference plane constituted by, for example, a horizontal plane determined by the spirit-level.

5.413 Tolerances

Permissible deviations of parallelism of straight lines or plane surfaces are given as follows:

error of parallelism: ... µm or mm,
... fraction of inch, or inch.

If the parallelism is to be checked only on a given length, this length shall be indicated e.g.:

0,02 mm on 300 mm,
0.001 in per ft or per 10 in.

As a rule, the direction of the deviation is not important; however, if the error of parallelism is to be allowed only in one direction, the direction shall be indicated, e.g.:

free end of the spindle in an upward direction only (relative to the table surface).

It should be remembered that the tolerance on parallelism includes the tolerance of form of corresponding lines and surfaces and that the results of a check depend on the plunger surface, which should, when required, be stated.

5.42 Parallelism of motion

5.421 Definition

The term *parallelism of motion* refers to the position of the trajectory of a moving part of the machine in relation to:

— a plan (support or slideway);

— a straight line (axis, intersection of planes);

— a trajectory of a point on another moving component of the machine.

5.422 Methods of measurement

5.422.1 General

Methods of measurement are, as a rule, identical with those used for tests of parallelism of lines and planes.

Whenever tests involve movement of the measuring instruments, the instrument should be fixed to the moving component, i.e. the moving component should take the place of the supporting base of the dial gauge.

The moving component shall, as far as possible, be driven in the usual way, so as to allow for the effect of play and errors in slideways.

5.422.2 Parallelism between a trajectory and a plane

5.422.21 Plane is on the moving component itself

The dial gauge is attached to a fixed component of the machine, and the plunger bears at right-angles to the surface to be tested. The moving component should be moved by the amount stated (see figure 32).

5.422.22 Plane is not on the moving component itself

The measuring instrument is attached to the moving component and moved with it by the amount stated; the plunger is at right-angles to the surface and slides along it (see figure 33).

If the plunger cannot bear directly on the surface (e.g. the edge of a narrow groove), a piece of suitable shape may be used (see figure 34).

5.422.3 Parallelism of a trajectory to an axis

The measuring instrument is fixed to the moving component and is moved with it by the stated amount: the plunger slides over the cylinder or mandrel representing the axis (see figure 35).

Unless all planes are of equal importance, the check shall be made, if possible, in two perpendicular planes selected as being those most important for the practical use of the machine.

5.422.4 Parallelism of a trajectory to the intersection of two planes

Parallelism between each of the two planes and the trajectory shall be tested separately, according to 5.422.2; the position of the intersecting line is deduced from the position of the planes.

5.422.5 Parallelism between two trajectories

A dial gauge is attached to one of the moving components of the machine so that its plunger rests on a given point on the other moving part. The two parts are moved together in the same direction by the same amount stated, and the variation in the reading of the measuring instrument is noted (see figure 36).

Unless all planes are of equal importance, this check shall be made in two perpendicular planes selected as being those of most importance in the practical use of the machine.

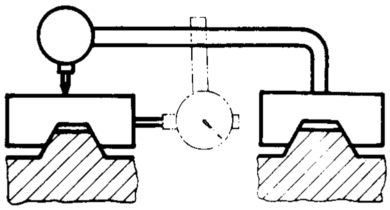


Figure 30

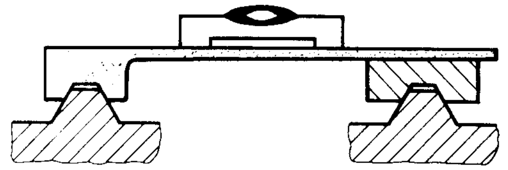


Figure 31

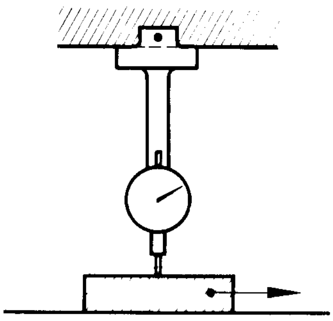


Figure 32

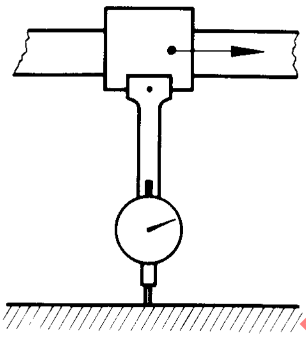


Figure 33

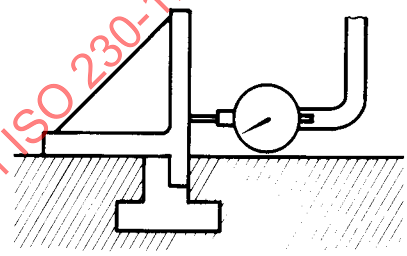


Figure 34

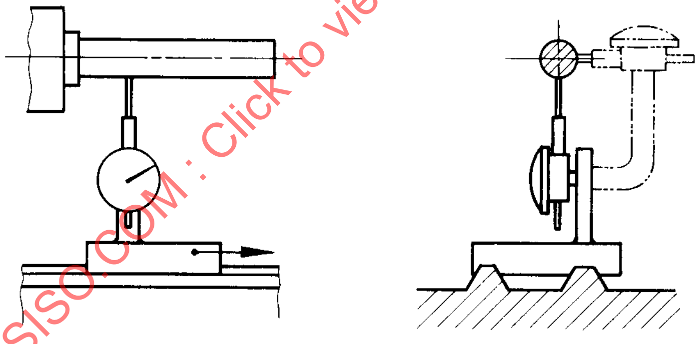


Figure 35

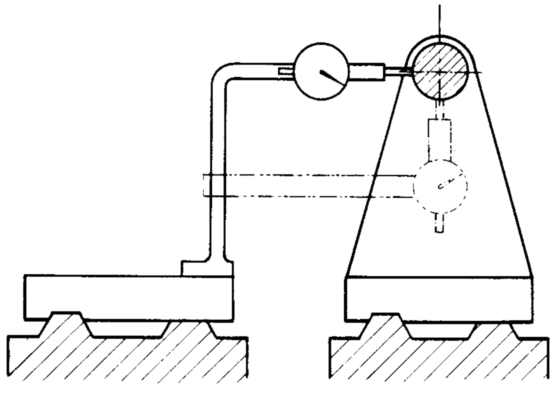


Figure 36

5.423 Tolerance

Tolerance on parallelism of movement is the permissible variation in the shortest distance between the trajectory of a given point on the moving part and a plane, a straight line or another trajectory within a stated length.

For the method of determining the tolerance, see 5.413.

5.43 Equidistance

5.431 Definition

Equidistance relates to the distance between the axes and a reference plane. There is equidistance when the plane passing through the axes is parallel to the reference plane. The axes may be different axes or the same axis occupying different positions after pivoting.

5.432 Methods of measurement

5.432.1 General

The problem is identical with that of parallelism between a plane passing through the axes and a reference plane.

Tests for equidistance of two axes, or of a rotating axis, from a plane are, in effect, checks of parallelism (see 5.412.4). A test should first be made to check that the two axes are parallel to the plane, then that they are at the same distance from this plane, by using the same dial gauge on the two cylinders representing the axes (see figure 37).

If these cylinders are not identical, the difference of radius of the tested sections should be taken into account.

5.432.2 Special case of the equidistance of two axes from the plane of pivoting of one of the axes

The plane of pivoting of the part carrying one of the axes may not be accessible and may not allow movement of the measuring instrument. It will then be necessary to construct an additional plane parallel to the plane of pivoting (see figure 38).

The setting and fixing of this auxiliary plane should be carried out so that, when a level is placed on it, if possible in two perpendicular directions, there is no deviation during the pivoting motion of the component. The equidistance of the pivoting axis (in its middle as well as in its extreme positions) is then tested, as well as that of the fixed axis, in relation to the auxiliary plane.

NOTE — When either a horizontal or oblique auxiliary plane is used, it is recommended that the dial gauge be set in its original place to ensure that no abnormal displacement has taken place when pivoting.

5.433 Tolerance

The permitted difference of distance should not be preceded by a sign and shall be generally valid in all directions parallel to the reference plane.

If the difference is permissible in one direction only, the direction shall be specified, e.g. :

axis 1 higher than axis 2.

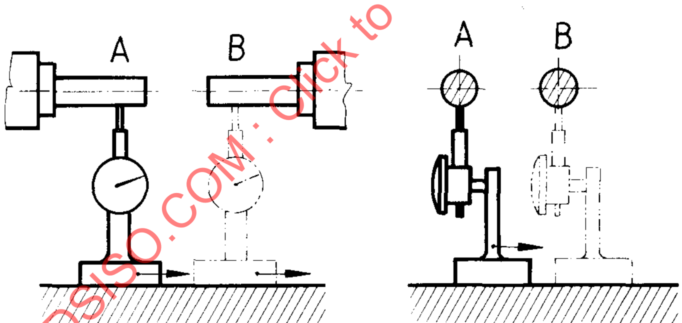


Figure 37

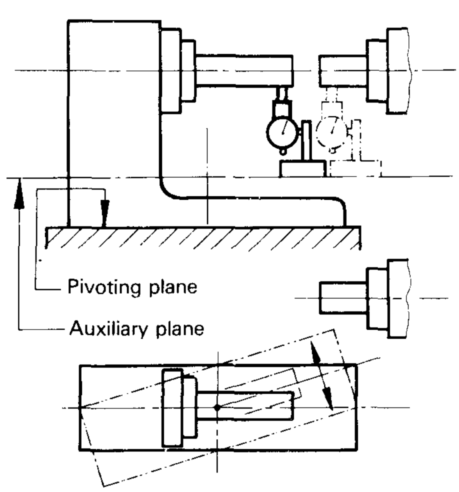


Figure 38

5.44 Coincidence or alignment[1]

5.441 Definition

Two lines or two axes are said to be *coincident* or *in alignment* when their distance apart at several points over a given length is measured both in amount and in position, and this distance does not exceed a given value. The distance measured may be located either on the actual lines or on their extension.

5.442 Method of measurement

The measuring instrument is attached to an arm and rotates through 360° around an axis. The plunger of the measuring instrument passes in a given section A over the cylinder representing the second axis (see figure 39). Any variation in the readings represents twice the error of coincidence. As the section chosen for measuring may intersect both axes, the check shall be made in a second section B.

If the error is to be determined in two specified planes (e.g. planes H and V on the figure), the variations found in those two planes will be separately recorded.

It is necessary, particularly in the case of horizontal axes, to have very rigid mountings. When great accuracy is required, two measuring instruments, offset by 180°, shall be used simultaneously in order to eliminate the effect of deflection. Alternatively, a support shall be used, the deflection of which is negligible under a weight equal to double that of the dial gauge used. Dial gauges of very light weight shall be used in these tests.

Since the direction of the measurement will vary during rotation in relation to the direction of gravity, the sensitivity of the test apparatus to the force of gravity shall be taken into account.

When one of the two axes is an axis of rotation, the arm carrying the measuring instrument may be fixed to the mandrel representing the axis around which rotation will be effected. If the measuring instrument is required to rotate around a fixed cylinder, it should be mounted on a ring rotating with a minimum amount of play. This ring should be of sufficient length to ensure that the reading is not affected by play in the ring (see figure 40).

If both axes are axes of rotation, the cylinder to be tested may be brought to the mean position of its run-out in the test plane (see 5.412.1).

5.443 Tolerance

When the direction of the permissible deviations in alignment of two axes (or two lines) does not matter, the tolerance is given as follows:

error of alignment of axis 1 to axis 2... µm or mm (or fraction of an inch) over a given length.

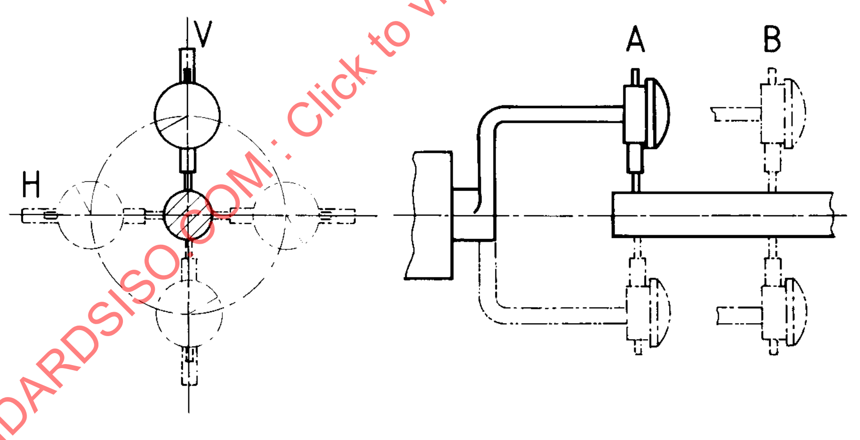


Figure 39

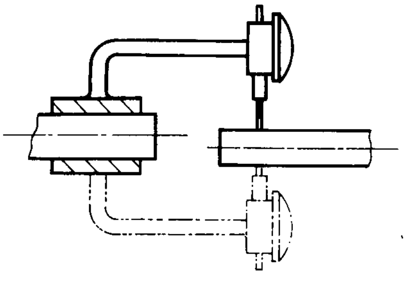


Figure 40

1) The word *alignment* is sometimes used in workshops with the much more general meaning of parallelism. Here it refers only to two axes merged in each other or where one axis extends beyond the other.

In special cases, an additional indication depending on operating conditions may be given, for instance:

axis 1 only higher than axis 2, or

free end of axis 1 directed only outwards in relation to axis 2.

In other cases, it may be useful to insert, in addition to the tolerance on coincidence, a further tolerance on parallelism between the two axes (see figure 41).

a) Error of alignment of axis 1 to axis 2: T µm or mm (or fraction of an inch) over a given length.

b) Error of parallelism between axis 1 and axis 2: T' µm or mm (or fraction of an inch) over a given length ($T' < T$).

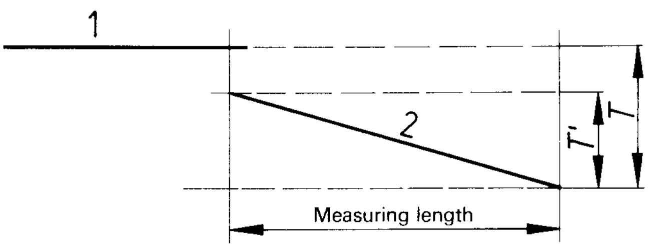


Figure 41

5.5 Squareness

The checks comprise the following points:

- squareness of straight lines and planes, see 5.51;
- perpendicularity of motion, see 5.52.

5.51 Squareness of straight lines and planes

5.511 Definition

Two planes, two straight lines or a straight line and a plane are said to be *perpendicular* when the error of parallelism in relation to a standard square does not exceed a given value. The reference square may be a metrological square or a right-angle level, or may consist of kinematic planes or lines.

5.512 Methods of measurement

5.512.1 General

The checking of squareness is, in practice, the checking of parallelism. The following general notes apply.

For an axis of rotation, the following method may be used. An arm carrying a dial gauge is attached to the spindle and the plunger of the gauge adjusted parallel to the axis of rotation. As the spindle revolves, the dial gauge describes a circumference, the plane of which is perpendicular to the axis of rotation. By measuring the plane to be checked by means of the plunger of the dial gauge, the deviation of parallelism between the plane of the circumference and the plane tested may be ascertained.

This deviation is expressed in relation to the diameter of the circle of rotation of the instrument (see figure 42).

1) If no test plane is specified, the dial gauge is rotated through 360° and the largest variation in the readings of the instrument taken.

2) If test planes are specified (e.g. planes I and II), the difference of the reading in the two positions of the dial gauge, 180° apart, should be noted for each of these planes.

In order to eliminate the effect of periodic axial slip (see 5.621.2) of the spindle, which may make the checking inaccurate, a fixture with two equal arms may be used to carry two measuring instruments, offset by 180°, and the mean of their readings taken.

The test may also be verified with only one dial gauge. After the first test, the instrument is moved through 180° relative to the spindle, and the test repeated.

Finally, the minimum axial play shall, if necessary, be eliminated by means of a suitable axial pressure (see 5.621.1).

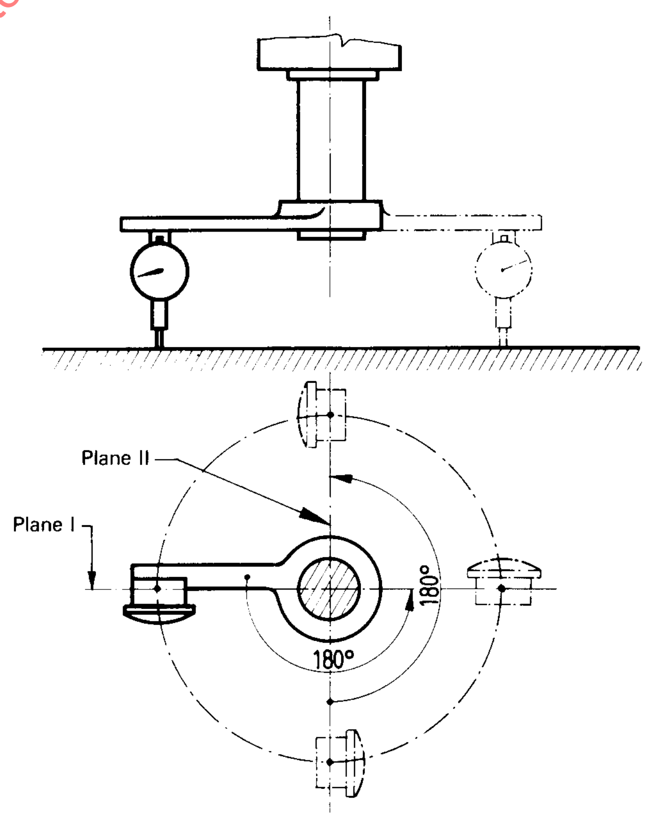


Figure 42

5.512.2 Two planes at 90° to each other

A square is set on one of the planes (see figure 43). The parallelism of its free arm to a second plane is checked by the method described in connection with checking for parallelism (see 5.412.2 or 5.412.4).

It is recommended that the free arm of the square should be cylindrical, so that the least distance may be found by lateral movement of the dial gauge.

5.512.3 Two axes at 90° to each other

5.512.31 The two axes are fixed axes

A square with a suitable base is placed on the cylinder representing one of the two axes (see figure 44). Parallelism between the free arm and the second axis is tested by the method described in connection with checking of parallelism (5.412.4).

5.512.32 One of the axes is an axis of rotation

A dial gauge is attached to an arm fitted to the mandrel representing the axis of rotation and is brought into contact with two points A and B on the cylinder representing the other axis (see figure 45). Variation in the readings is expressed in relation to distance AB.

If the second axis is also an axis of rotation, the cylinder representing it is brought into the mean position of the run-out in the plane of measurement, according to the method described in connection with the checking of parallelism (see 5.412.1).

5.512.4 An axis and a plane at 90° to each other

5.512.41 Fixed axis

A square with a suitable base is brought into contact with the cylinder representing the axis (see figure 46).

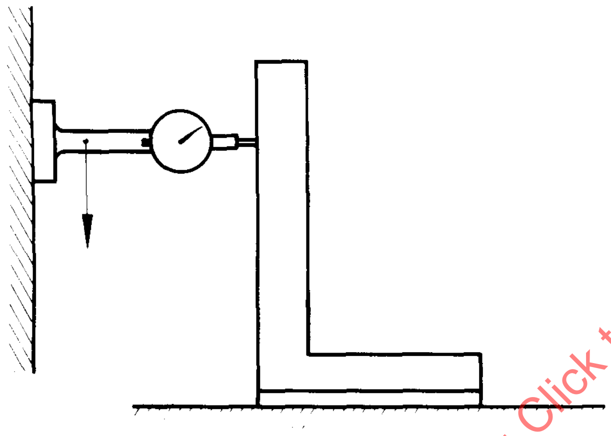


Figure 43

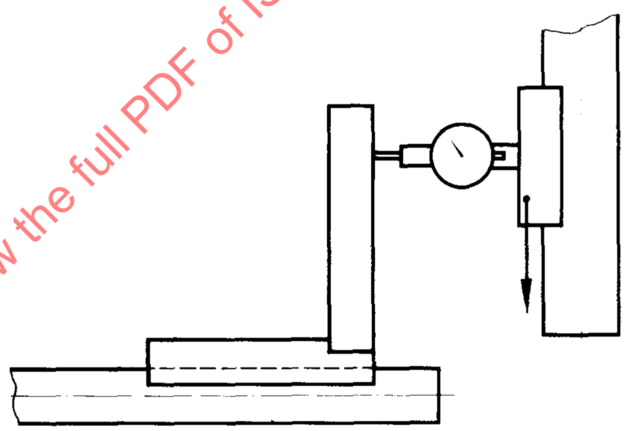


Figure 44

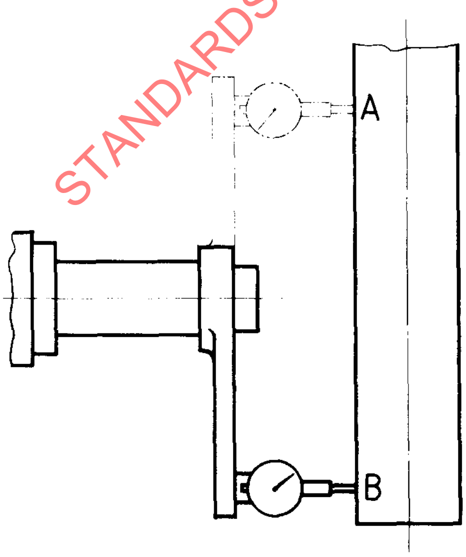


Figure 45

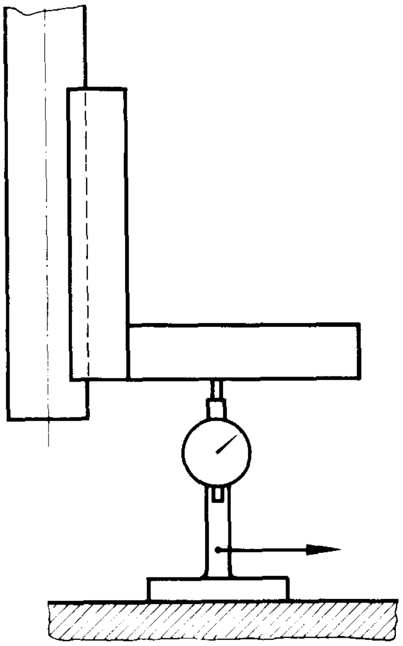


Figure 46

Parallelism of the free arm to the plane is tested in two perpendicular directions by the method given in connection with checking of parallelism (see 5.412.2).

5.512.42 Axis of rotation

A dial gauge is attached to an arm fixed on the spindle and the operation is as given in 5.512.1.

5.512.5 An axis at 90° to the intersection of two planes

5.512.51 When the axis is fixed

A square with a suitable base is brought into contact with the cylinder representing the axis (see figure 47). Parallelism between its free arm and the intersection is tested by the method proposed in connection with checking of parallelism (see 5.412).

5.512.52 When the axis is an axis of rotation

A dial gauge is attached to an arm held on the spindle, the plunger being against a block which rests on the two intersecting plane surfaces. The spindle is given half a turn and the V-block moved so as to bring the plunger into contact with the same point on the block (see figure 48).

5.512.6 When the intersection of two planes is at 90° to another plane

A square (see figure 49) or a dial gauge (see figure 50), as appropriate, is fitted with a suitable base, allowing it to rest on the intersecting planes.

Parallelism between its free arm and the third plane or the intersection may be tested by the method described in connection with checking of parallelism (see 5.412.2 or 5.412.6). The test shall be made as far as possible in two perpendicular planes [see figure 50a) and b)].

5.512.7 When two straight lines, each formed by the intersection of two planes are at 90° at each other

A square of suitable base is placed on one of the intersections. The test whether the free arm is parallel to the second straight line of intersection is made by the method described in connection with checking of parallelism (see 5.412.6).

NOTE — If direct checking of the planes and straight lines concerned is difficult owing to the distance between them, or to interference by components, the test may be made in relation to a reference plane, e.g. by the use of a water surface or a level.

5.513 Tolerance

The permissible errors in the perpendicularity of straight lines or flat surfaces, when the error relating to the right angle can be in either of two directions, are given as follows:

errors relating to the right angle: ± ... µm or mm
(± ... in), on a given length.

When the errors are determined in relation to another part of the machine, this part should be indicated, for instance:

free end of the spindle inclined only towards the support.

5.52 Checking of perpendicularity of motion

5.521 Definition

The term *perpendicularity of motion* refers, for machine tools, to the successive positions on the trajectory of a point on a moving part of the machine in relation to

- a plane (support or slideway);
- a straight line (axis or intersection of two planes);
- the trajectory of a point on another moving part.

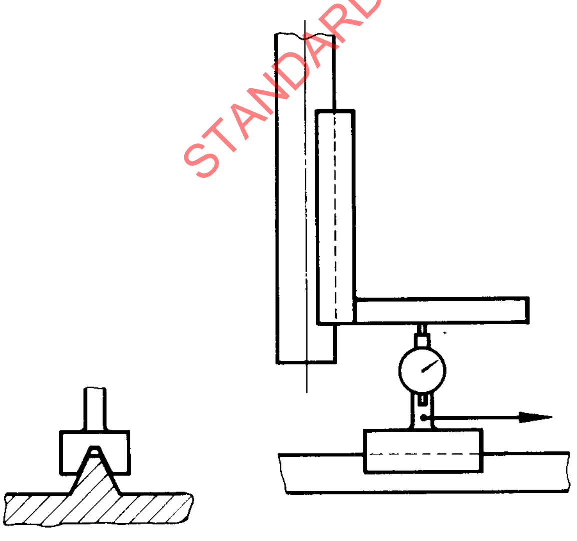


Figure 47

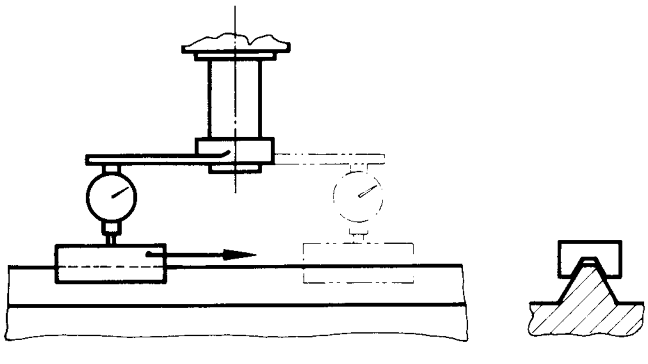


Figure 48

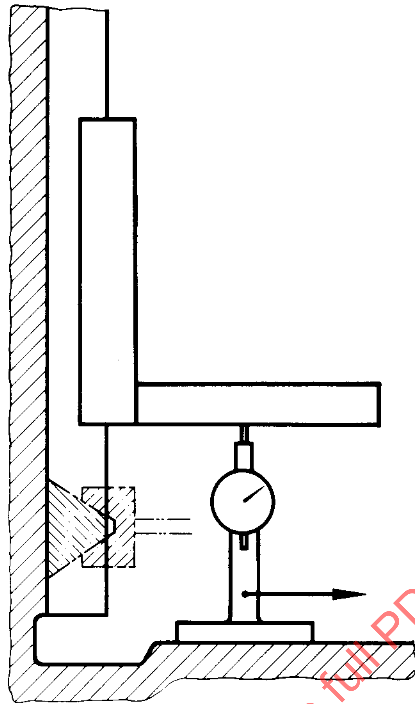


Figure 49

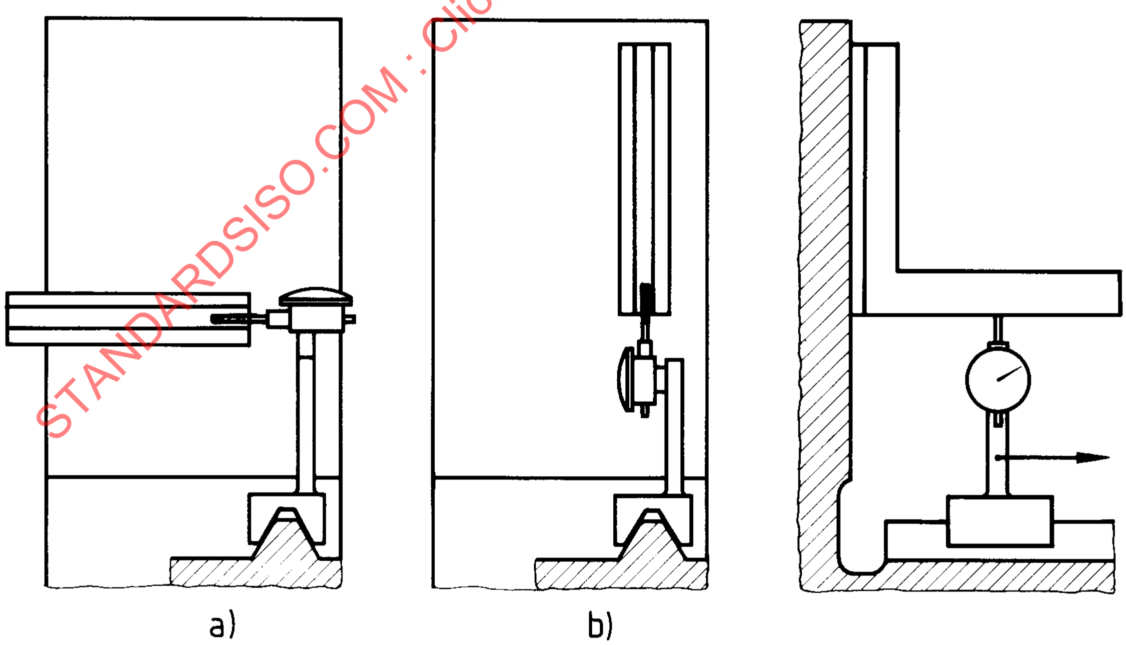


Figure 50

5.522 Methods of measurement

5.522.1 General

The checking of perpendicular motion becomes a test of parallelism by the use of a square suitable for the given conditions (see 5.232).

The moving part should be driven in the usual way so as to allow for the effects of play and errors in slideways.

5.522.2 Perpendicularity between the trajectory of a point and a plane

A square is placed on the plane (see figure 51). Parallelism between the motion and the free arm shall be tested in two perpendicular directions, in accordance with 5.422.22.

5.522.3 Trajectory of a point at 90° to an axis

A square, with a suitable base, is placed against the cylinder representing the axis (see figure 52). The test for motion parallel to the free arm of the square shall be made in accordance with 5.422.22.

If the axis is one of rotation, the mandrel representing the axis shall be placed in the mean position of its run-out in the test plane. In the particular case of a lathe headstock spindle, capable of taking a face plate, it shall be possible to mount a flat ground disc. The face plate itself should not be used, as it never is absolutely flat. A second reading is made on the disc after rotating the spindle through 180°. The mean will give the deviation over the measured length. The axis may also be used, as indicated in 5.512.42, the trajectory being represented by a straightedge parallel to the latter.

5.522.4 Two trajectories perpendicular to each other

The two trajectories are compared by means of a square suitably mounted on gauge blocks and straightedges. An example of the test assembly is shown in figure 53.

One arm of the square may be lined up exactly to the trajectory I, by means of a dial gauge, and the trajectory II tested in accordance with 5.42.

The arm of the square may also be set parallel to the trajectory I with a greater inclination than the tolerance, so as to allow the dial gauges to work in one direction only, eliminating their drag. In the latter case, the error of perpendicularity shall be equal to the difference in the variations of the readings of the two dial gauges for the same range of measurement.

The deflection of the components caused by the loads supported may need to be taken into consideration.

This check may also be carried out by means of optical methods (see figure 54).

5.523 Tolerance

Tolerance of the perpendicularity of a given motion is the permissible variation within a given length (e.g. 300 mm), of the shortest distance between the trajectory of a point on a moving component of the machine and the free arm of a square. This variation is preceded by a ± sign.

For the method of determining the tolerance, see 5.513.

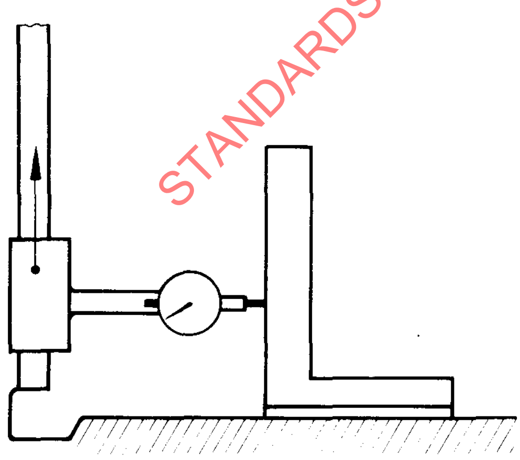


Figure 51

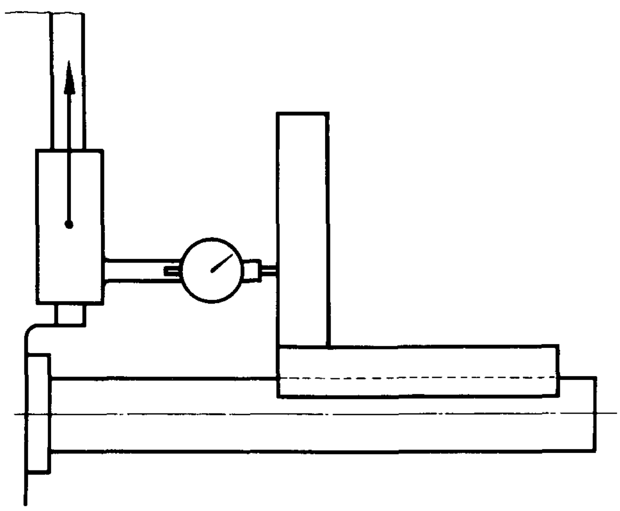


Figure 52

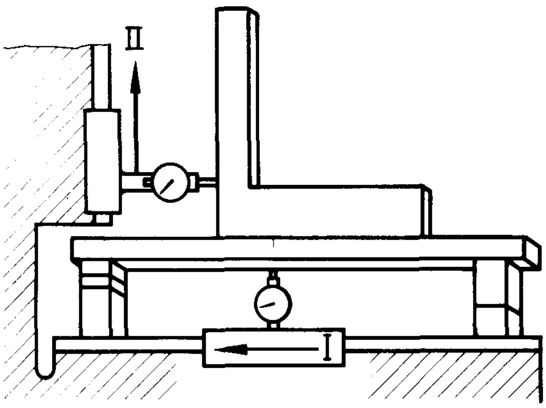


Figure 53

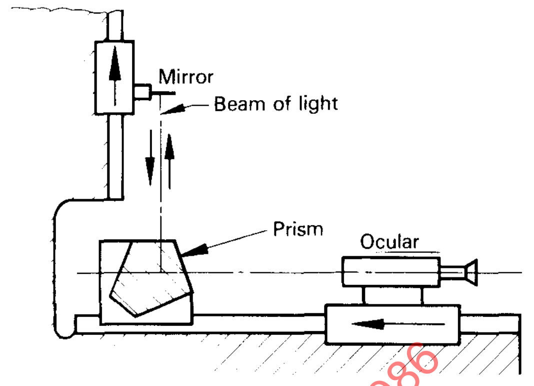


Figure 54

5.6 Rotation

The checks comprise the following points:

- run-out, see 5.61;
- periodic axial slip, see 5.62;
- camming, see 5.63.

5.61 Run-out

5.611 Definitions

5.611.1 Out-of-round

Error relative to the circular form of a component in a plane perpendicular to the axis at a given point of the latter.

For a shaft, the value of the out-of-round is given by the difference between the diameter of the described circle and the smallest measurable diameter of the shaft.

For a hole, it is given by the difference between the diameter of the inscribed circle and the largest measurable diameter of the hole, each of them measured in a plane perpendicular to the axis.

With the ordinary methods of measurement, this definition cannot be strictly applied in practice. However, when the out-of-round of a component is measured, this definition should be kept in mind and the method used should be chosen so that the results are as far as possible in accordance with the definition.

NOTE — Ovality is a special case of out-of-round.

5.611.2 Eccentricity (see figure 55)

Distance between two parallel axes when one is rotating round the other. (Eccentricity is not an error, but a dimension subject to tolerances; it should not be confused with the defect named in French "excentrement").

5.611.3 Radial throw of an axis at a given point

In a part the geometrical axis of which does not coincide exactly with the rotating axis (error of concentricity), the distance between the intersections of these two axes with a plane perpendicular to the axis of rotation at a given point (see figure 56).

5.611.4 Out-of-true running (run-out) of a component at a given section

If no account is taken of the out-of-round, the out-of-true running is twice the radial throw of the axis in a given section (see figure 56).

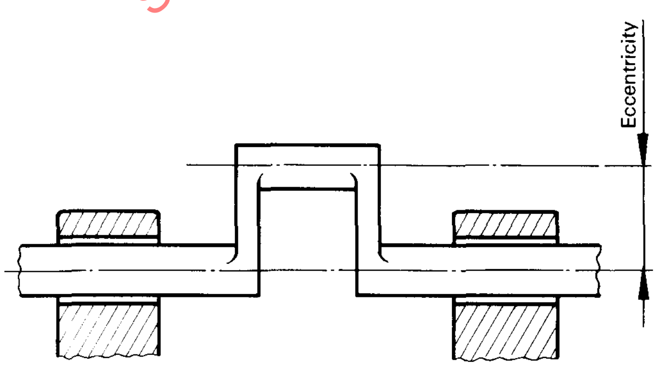


Figure 55

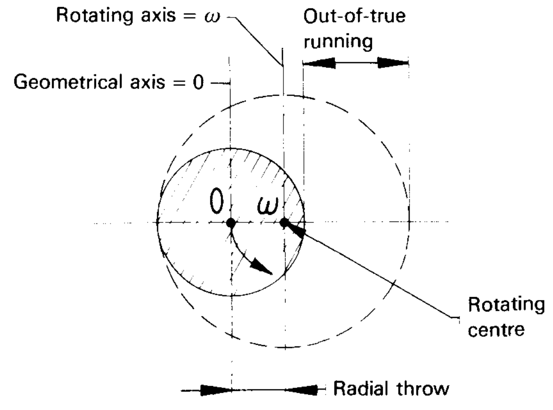


Figure 56

In general, the measured run-out is the resultant of

the radial throw of the axis,

the out-of-round of the component, and

the errors of bearings.

IMPORTANT NOTE — In geometrical testing of machine tools, the radial throw of an axis is measured by observing the run-out of a part mounted on the axis. In order to avoid any confusion in the minds of the personnel in charge of machine testing, and to eliminate any risk of error, only the words *run-out* are used in this part of ISO 230, and the indicated tolerance to be given has been applied systematically to this run-out so that the readings of the measuring instruments are not be divided by two. The proposed measuring methods take this note into consideration.

From the metrological point of view, the bearing of a cylindrical or conical surface is said to have an axis exactly *coincident* with a rotating axis if, on measuring over a given length (after fixing a test mandrel in this bearing, if necessary), the error of rotation at each measuring point does not exceed the specified value.

5.612 Methods of measurement

5.612.1 Precautions before testing

Before the check is carried out, the spindle shall be rotated sufficiently to ensure that the lubrication film will not vary during the test and that the temperature attained can be considered as the normal running temperature of the machine.

5.612.2 External surface

The plunger of a dial gauge is brought into contact with the revolving surface to be tested and the readings of the instrument observed while the spindle is slowly rotated through one turn (see figure 57).

On a conical surface, the plunger is set at right-angles to the generating line; the diameter of the circle being checked will vary if there is any axial movement in the spindle during its rotation. This causes the run-out to appear greater than it actually is. Therefore a conical surface shall only be used for checking run-out if the taper is not steep. The axial slip (see 5.621.2) of the spindle is in any case measured previously, and its possible effect on the measurements is computed according to the angle of taper.

5.612.3 Internal surface

If the dial gauge cannot be used directly on a cylindrical or tapered bore, a test mandrel is mounted in the bore. The projecting cylindrical part of this mandrel shall be used for the test, in accordance with the previous clause. However, if the test is made at one section only of the mandrel, the position of only one circle of measurement in relation to the axis should be determined. As the axis of the mandrel may cross the axis of rotation in the measurement plane, checking should be done on two sections A and B which are a specified distance apart (see figure 58).

For instance, one test should be made close against the housing of the mandrel and another at a specified distance from it. To provide for any lack of accuracy in inserting the mandrel into the bore, particularly with tapered bores, *these operations shall be repeated at least four times, the mandrel being turned through 90° in relation to the spindle. The average of the readings shall be taken.*

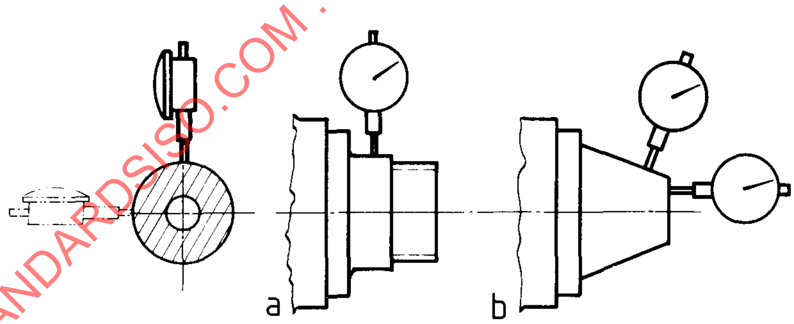


Figure 57

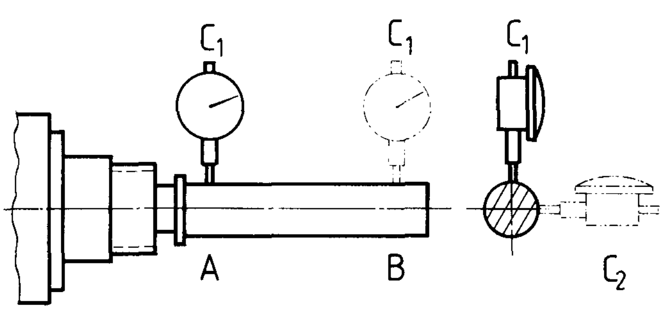


Figure 58

In each case, the run-out shall be measured in a vertical axial plane and then in a horizontal axial plane (positions C_1 and C_2 in figure 58).

The above methods require the following comments.

As the movement of the plunger may vary directionally during the checking of run-out, every guarantee shall be afforded for the accuracy of the measuring instrument (minimum drag).

When checking with a test mandrel, the exact shape of the bore is not checked.

A check of the run-out of the spindle by machining and testing a cylindrical workpiece will take into account only errors in the bearings of the spindle. This turning test therefore gives no information on the exact shape of the cylindrical or conical bore, or of the actual position of the bore in relation to the axis of rotation.

The above methods apply only to spindles in plain bearings or ball and roller bearings. Spindles which are automatically centred during rotation (e.g. by hydraulic pressure) can only be tested when running at normal speed. In such a case, instruments involving no contact shall be used, e.g. a capacitative pick-up, an electro-magnetic pick-up or any other suitable instrument.

5.613 Tolerance

The tolerance on the run-out is the deviation permissible in the trajectories of points on a section of the revolution surface. It is not preceded by a sign. It includes errors in the shape of the revolving surface, the movement and the lack of parallelism of the axis of this surface in relation to the axis of rotation (errors of position) and the movement of the axis of rotation if bearing surfaces or bores are not exactly circular (errors of bearings). For surfaces of small dimensions in the direction of their axis (e.g. a spindle nose of a grinding machine), it is sufficient to have one test plane, but, for longer surfaces, the reference planes shall be specified.

When it is desired to specify the checking of the run-out only in a given plane or over a specified length, this plane or this length shall be stated.

5.62 Periodic axial slip

5.621 Definitions

5.621.1 Minimum axial play

The smallest value of possible axial movement of a rotating part, measured at rest at each of the several positions around its axis (see figure 59).

5.621.2 Periodic axial slip

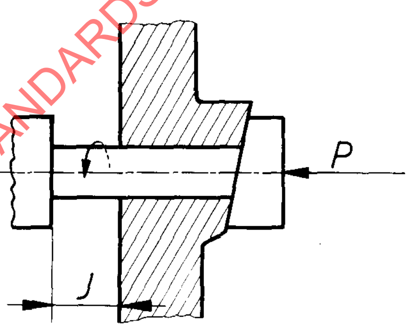
Extent of reciprocating motion along the axis of a rotating part, when the latter is rotated, eliminating the influence of the minimum axial play by axial pressure in a given direction (see figure 59).

When the axial slip of a rotating part remains within the tolerance zone, this part may be considered as fixed in its axial direction.

5.622 Methods of measurement

5.622.1 General

In order to eliminate the effect of play in thrust bearings, a slight pressure shall be applied to the spindle in the direction of measurement. The plunger of the dial gauge should be applied to the centre of the front face and aligned as well as possible along the axis of rotation. Readings are taken while the spindle is rotated continuously at slow speed, pressure being maintained meanwhile in the stated direction.



J = Maximum axial play
j = Minimum axial play
d = Periodic axial slip

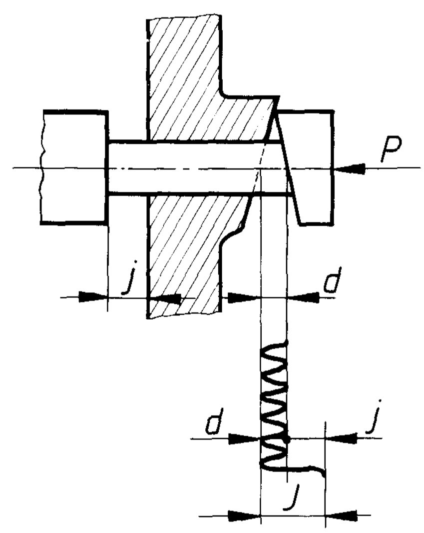


Figure 59

If the spindle is hollow, a short mandrel should be fitted with a plane face perpendicular to the axis against which a plunger with a rounded contact point may bear (see figure 60). Alternatively, a mandrel with a rounded face may be used with a plunger having a flat contact point (see figure 61). If the spindle has a centre, a steel ball should be inserted for a flat contact point to bear against (see figure 62).

5.622.2 Applications

Periodic axial slip may be measured with a device which permits a force to be applied along the axis and a dial gauge to be placed on the same axis (see figure 63).

The same applies to lead screws and rotating face plates.

For a lead screw, the axial force can be applied by movement of the slide when the nut is connected. Horizontal rotating face plates are sufficiently supported on the thrust bearings by their own weight.

The value of the axial slip may be obtained approximately by applying a force along the axis and placing the dial gauge not exactly on the axis, but at a small distance from it. In these conditions the lack of flatness and the slope of the face over which the plunger passes, which are generally very small, do not seriously affect the measurement, but, in this case, a test should be made for each of the two positions at 180° of the dial gauge and the algebraic mean of the readings taken.

This last method is generally used when testing the periodic axial displacement of the spindle of a lathe or a milling machine, e.g. testing during which a plunger is used on the face of the face plate or on the front of the spindle nose (see figure 64).

NOTE — If the thrust bearing is of the ball or roller type, the test should be made through at least two revolutions.

Since the movement of the plunger may vary directionally during this test, every guarantee should be afforded for the accuracy of the measuring instrument (minimum drag).

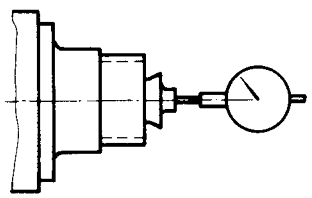


Figure 60

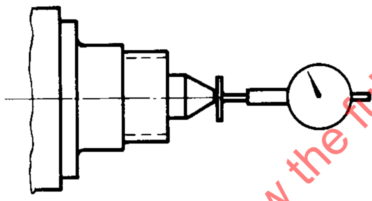


Figure 61

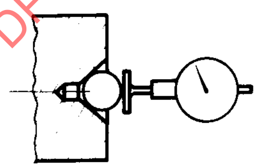


Figure 62

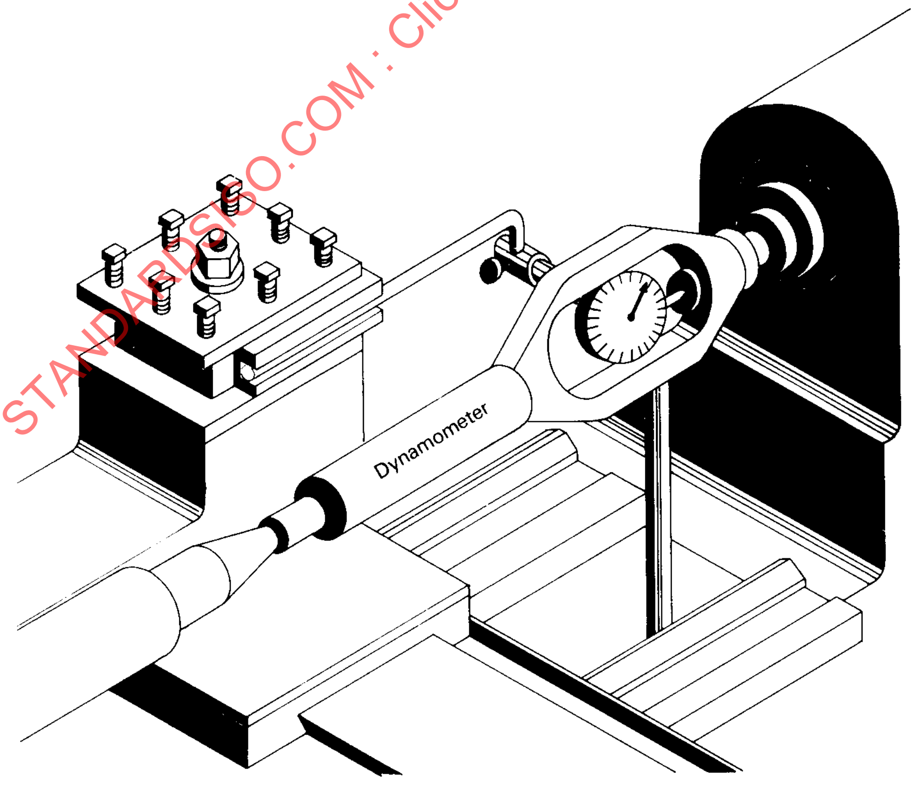


Figure 63

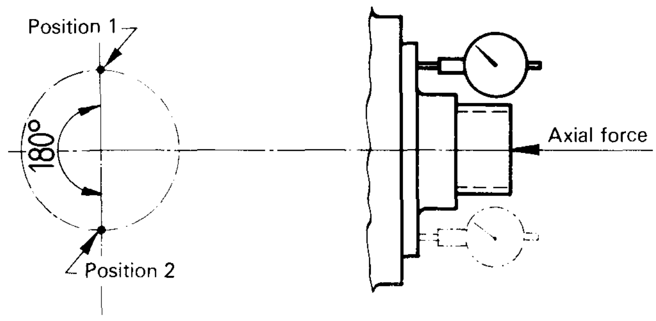


Figure 64

5.623 Tolerance

The minimum permissible axial slip defines the limit of the axial slip of the spindle during one slow rotation with a slight axial pressure. The direction of this pressure should be indicated (e.g. "applying a slight pressure towards the housing"). It may be necessary to make two tests, by applying the pressure first in one direction and then in the opposite direction; in this case, different tolerances for the two directions may be stated.

5.63 Camming

5.631 Definitions

5.631.1 Camming of a plane surface rotating around an axis

a) Camming of the surface

Camming is the defect of a plane surface which, when rotating around an axis, does not remain in a plane perpendicular to this axis. Camming is given by the distance H separating the two planes perpendicular to the axis, between which the points of the surface are moving during the rotation.

b) Camming of the surface at a distance d from the axis

This is represented by the distance h separating two planes perpendicular to this axis, between which the portion of surface delineated by a revolving cylinder moves, the diameter of which is $2d$, and which has, as its axis of symmetry, the theoretical axis of rotation of the surface.

Camming is the resultant of various defects of the surface and axis of rotation (h_1, h_2, h_3); see figure 65 a), b) and c):

a) surface not flat;

b) surface and axis of rotation not perpendicular;

c) periodic axial displacement of the axis.

NOTE — When the plane concerned has a geometrical axis (part A, figure 66) which does not coincide with the axis of rotation, the resulting radial throw gives camming. This defect is due to a lack of perpendicularity of the face to the axis of rotation. In practice, the run-out does not have a great effect, as it affects camming only in the ratio 1:2. When the run-out is constant on all points of the axis (eccentricity), there is no camming.

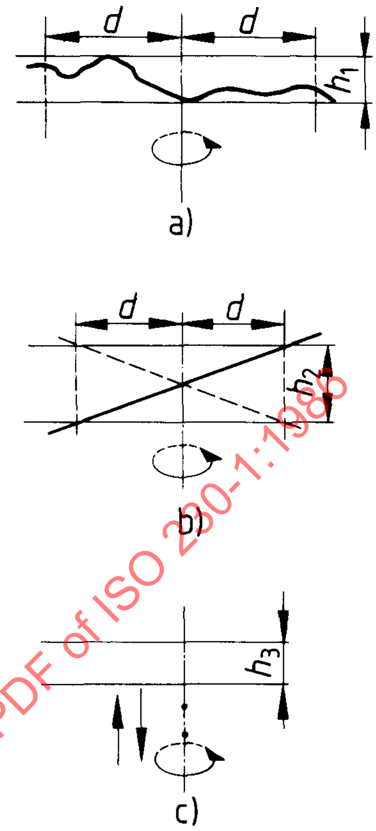


Figure 65

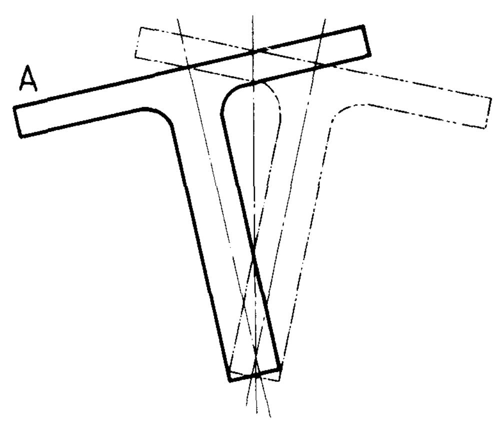


Figure 66

5.632 Method of measurement

The checking of camming relates to rotating face plates. The object is to verify that all the points in the same circle on the front face are in the same plane perpendicular to the axis of rotation and that the axial position of this plane does not vary during the rotation of the spindle. As camming tends to increase the farther its distance is away from the axis of rotation, testing shall be done on the circumference corresponding to the points farthest from the axis.

The dial gauge shall be applied at a given distance A from the centre and at right-angles to the face (see figure 67), and placed successively at a series of points spaced around the periphery. The deviations between the maximum and minimum readings will be noted at each of these points: the greatest deviation will be the camming.

The spindle should make continuous revolutions at slow speed, and should receive a slight end-pressure to eliminate the effect of play in the thrust bearings; horizontal face plates are, as already indicated (see 5.622.2) sufficiently supported on their thrust bearings by their own weight.

The direction in which slight pressure is applied to the spindle during the test should be specified e.g.: "applying slight pressure towards the housing".

NOTE — If it is desired to analyse the origin of the camming, the defects of the surface and those of the axis should be measured separately. The axial displacement of the axis should in any event be measured. If the face plate has been machined after mounting (i.e. machined on the machine tool itself to which the face plate belongs), the dial gauge may remain at zero when it takes the place of the tool. The setting of the plunger, at 180° from this particular position, will give a camming h, the value of which is double the axial displacement.

5.633 Tolerance

The tolerance, which is measured in relation to a plane perpendicular to the rotating axis, represents the maximum permissible deviation, at any point, of all the trajectories of all the points on a given circumference of the surface to be checked. It includes errors of shape of the face, the angle of the latter in relation to the axis of rotation, the radial throw and the periodic axial slip of the spindle. *This tolerance does not, however, include the minimum axial play of the rotating component* (see figures 59 and 65).

6 Special checks

6.1 Division

6.11 Definition of errors

This clause deals with definitions of errors of division of graduated scales, gear wheels, dividing plates, pitch of driving screws, etc.

In general, the following errors may be recognised:

a) individual error of division;

b) successive error of division;

c) error of division in a given interval;

d) cumulative error (or steps in a given interval);

e) total error of division.

6.111 Individual error of division

The algebric difference between the actual value and the nominal value of the division.

Example: (ab – a'b') for the second division of figure 68 (a division is here considered as being the distance between two consecutive lines; several divisions form an interval).

6.112 Successive error of division

The actual deviation between two successive divisions; it is equal to the algebraic difference of the individual errors of two divisions.

Example: (ab – a'b') – (bc – b'c') = ab – bc in figure 68 for the second division, relative to the third division.

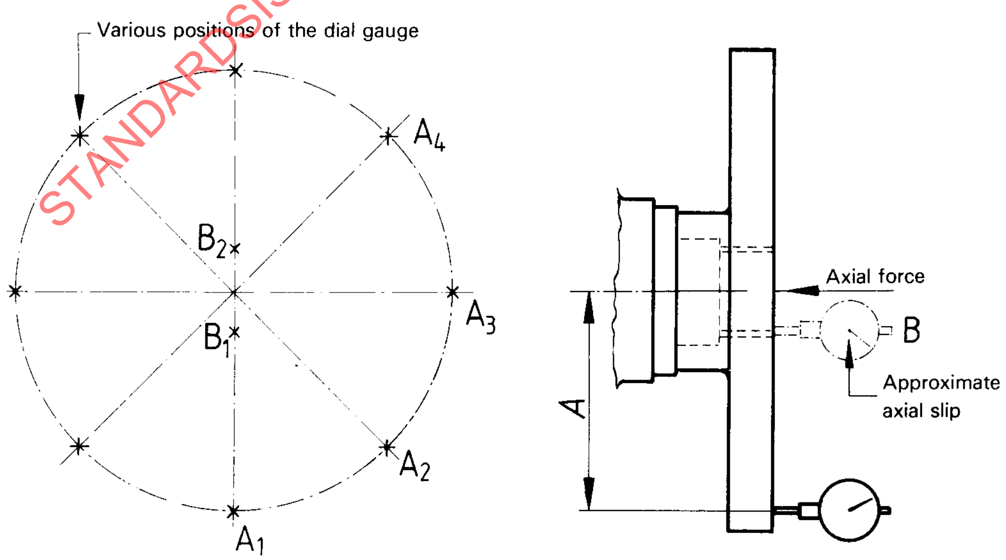


Figure 67

6.113 Error of division in a given interval

The sum of the magnitudes (absolute values) of the two greatest individual positive and negative errors in the interval.

Example: amplitude MN in interval 0 to 6 of figure 69.

If all the errors have the same sign in the specified interval, the error of division is equal to the largest of the absolute values of individual errors.

6.114 Cumulative error

The difference between the sum of the k first divisions and the theoretical nominal value of that sum. The step in the series may be determined by calculating the algebraic sum of the individual errors of each division or by comparing the actual position of the measuring instrument pointer with the position which it would have if the divisions were free from error (see figure 68).

6.115 Total error of division

The sum of the magnitudes (absolute values) of the greatest positive and negative steps included in the given interval. This interval may correspond to the whole of the scale, for instance 360°; amplitude RS in figure 71.

6.116 Graphical representation of these errors

Take a graduation scale, giving, with the theoretical scale, the steps indicated in figure 68:

1) If a diagram is drawn (see figure 69), showing as abscissae a series of divisions and as ordinates the individual errors, the maximum amplitude MN represents the local error of division in interval 0 to 6. For the whole series of the scale, this local error is represented by PH.

2) If a diagram is drawn showing as abscissae a series of divisions and as ordinates the successive errors of division (see figure 70), this diagram will allow the positions of the greatest errors in a given interval to be found.

3) If a diagram is drawn showing as abscissae a series of divisions and as ordinates the positive or negative differences of the actual position of every division in relation to its theoretical position (see figure 71), the maximum amplitude RS, shown by the diagram, represents the total error of division.

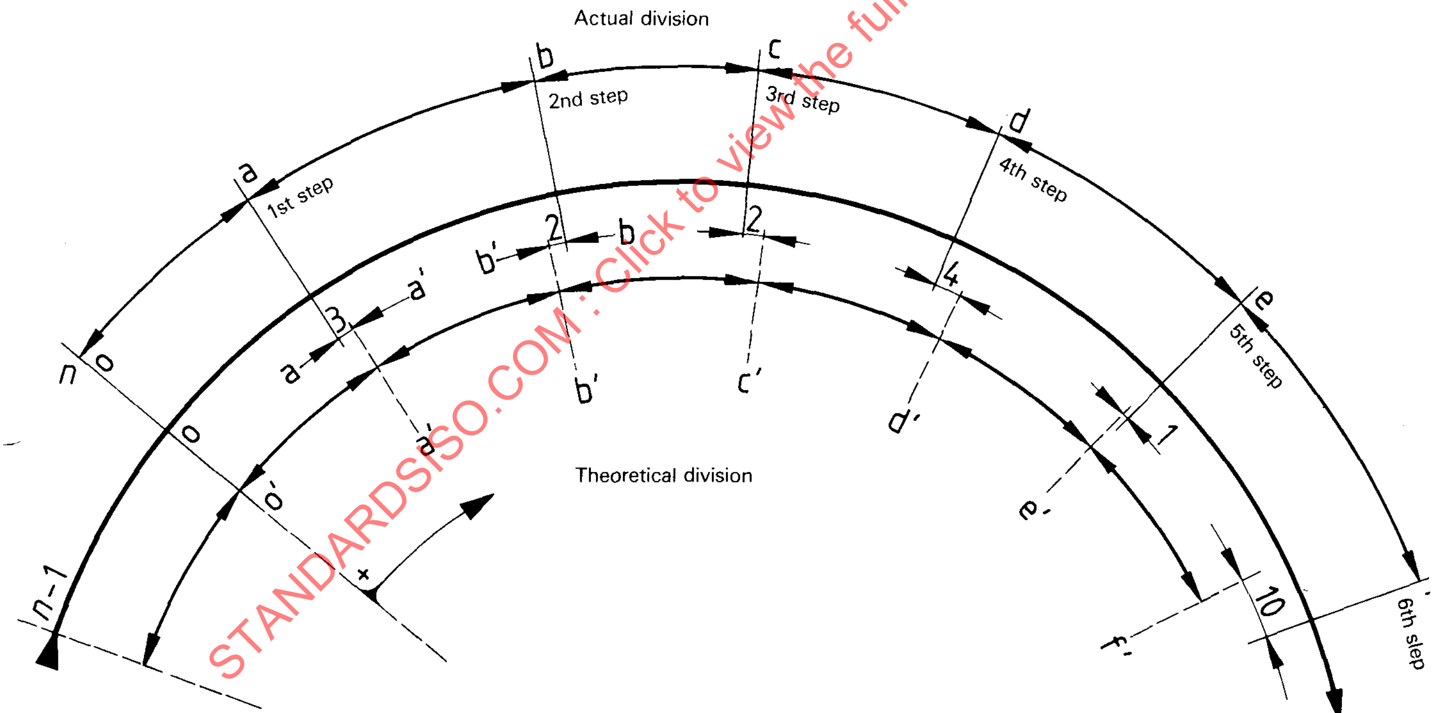


Figure 68

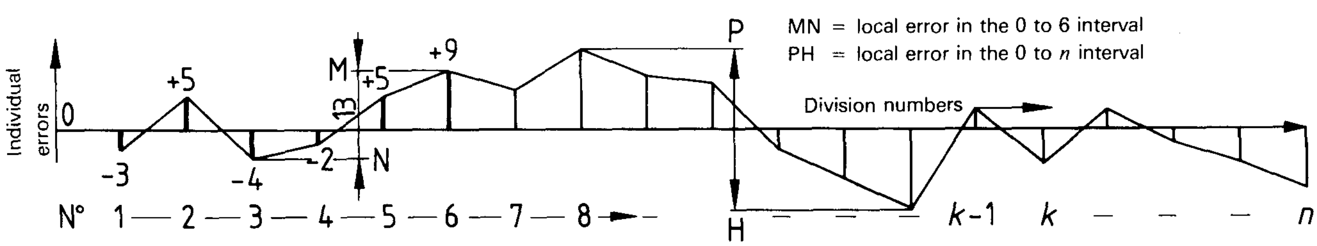


Figure 69 — Determination of local error

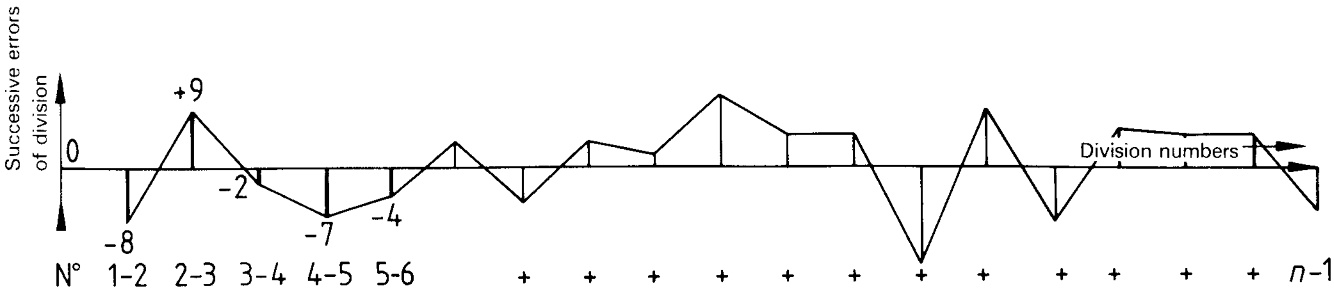


Figure 70 — Successive errors of division

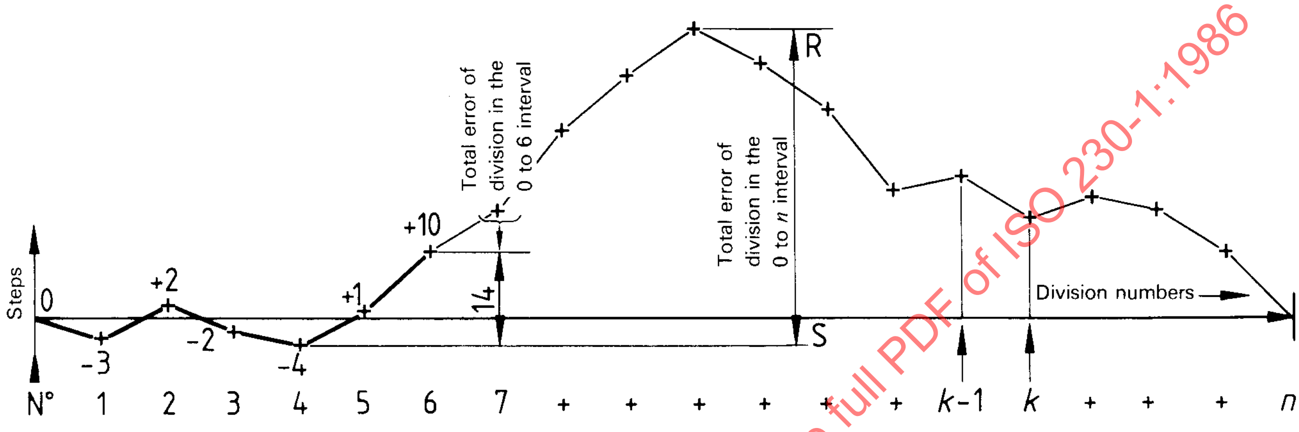


Figure 71 — Determination of the total error

It should be noted that figure 69 can be deduced from figure 71 as follows: the ordinate of step k of figure 69 is equal to the difference between the ordinates of the steps k and $k-1$ of figure 71.[1)]

6.12 Methods of measurement

As the checking of errors of division most often requires special devices, reference should be made to technical notes dealing with this question.

6.13 Tolerance

Usually, it is not necessary to fix tolerances for each of the five errors which have been defined. Thus, for linear divisions, the tolerance is always indicated for cumulative error (or step) in a given interval, e.g. 300 mm (or 12 in)]; for circular division, the individual and total errors are usually given.

NOTES

1 It should be observed that when testing machine tools, errors of division should normally include errors which may arise from the control devices used in the division. The individual values of partial errors (i.e.: errors of division properly so called, off-centre position of the scale in reference to the axis of rotation, play in components, etc.) constitute, when taken together, the total error. These partial errors are of little interest to the user of a machine tool.

2 Attention is also drawn to the fact that the accuracy given by a circular dividing mechanism, apart from the intrinsic accuracy of the dividing plate, is subject to the errors of concentricity of its mounting on the axis of the machine spindle.

6.2 Determination of the rectilinear deviations of screw-driven components

In order to check deviations, it may be necessary to examine, in their geometrical aspect, all the elements which might play a part in the deviations, and in particular the driving screw. Checking the pitch of this needs special equipment more often at the disposal of machine-tool builders or technical institutes than of users of machine tools. The accuracy of the pitch of the lead screw is only one of the numerous factors which control the accuracy of the displacement. Play in certain members and deflections may be important. It may be possible to attach to each of the factors concerned elementary tolerances in such a way that the overall tolerance corresponds to the precision expected of the machine.

In machine-tool testing, therefore, only the deviation of a screw-driven component need be determined by the use of geometrical checks or practical tests.

For a geometrical check, a dial gauge is mounted on the moving component, the driving screw is rotated and the corresponding displacement of the component is measured by means of gauge blocks. The result of this measurement shall then be compared with the displacement which the moving component should have made.

1) The individual error ab − a'b' can be put in the form (aa' + a'b) − (a'b + bb') or as (b'b − a'a): this expression represents the actual difference between each pair of lines of a given division (see figure 68).

For a practical test, a workpiece is machined and given lengths on it are measured; e.g., in the particular case of a lathe lead screw, a practical test may be carried out by setting up a workpiece on the machine at any point along the bed and rotating the lead screw over a maximum length of 300 mm. The pitch obtained on the workpiece shall then be checked, for instance, by means of a measuring machine.

6.3 Angular play

6.31 Definition

Angular play of a moving component is defined by the angle of displacement permitted by the play with may exist in its locking system when the component has been locked.

6.32 Method of measurement

Checking of lathe turrets: This test may be made by fixing a bar of sufficient length to effect a measurement over a known distance on the turret. At this distance, a dial gauge is mounted so that its plunger bears against the bar. A torque is exerted on the turret in one direction, then in the opposite direction, and differences are read off on the dial gauge. The value of the torque should be so selected as not to add any significant errors due to deflection of the component parts of the turret.

6.33 Tolerance

The tolerance is the tangent of the angle of displacement.

6.4 Trueness of devices with angular indexing
(e.g. turrets)

6.41 Definition

Lack of trueness is the angular deviation between the direction of a radius of the moving component and the direction of this same radius when, after rotating, the component is tried again at its original location.

6.42 Methods of measurement

The test may be made in the same way as the test for angular play, with a bar and a dial gauge. For a given indexing position, the moving component shall be rotated through one complete revolution. The difference between the readings made between successive locking represents the error of trueness corresponding to this position.

Measurements shall be repeated at each indexing position.

When the machine tool prevents a complete revolution, the moving component should be revolved through the largest possible fraction of a revolution, first in one direction, then in the opposite direction, so as to bring it back to its original position. The final movement should be made in the normal direction of running of the component. All movements should be made at the same speed, with a constant force applied for each clamping and each unclamping.

6.43 Tolerance

Tolerance of trueness is expressed by the tangent of the angle and includes the tolerance of the angular play (in fact, the tolerance of trueness cannot be fixed independently of tolerances of angular play).

6.5 Intersection of axes

6.51 Definition

Two non-parallel axes *intersect* if the shortest distance between them lies within the specified tolerance.

6.52 Method of measurement

The point of intersection of two non-parallel axes can be determined by means of measurements made between the shafts representing these axes. The method is the same as that for checking the equidistance of two axes with an additional plane (see 5.432.1). This check is easier if the shafts are replaced by two suitably machined bars, with a flat face in a plane parallel to their axis. Measurements are taken between the two flat faces to determine the error of intersection (see figure 72).

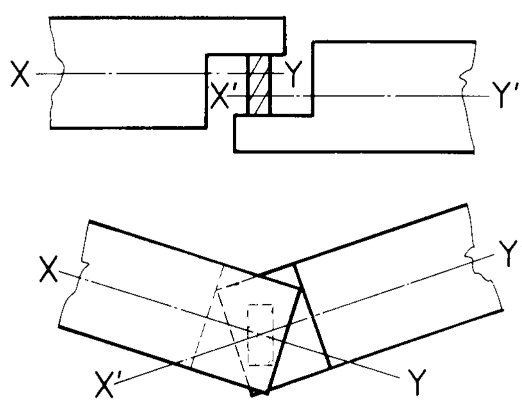


Figure 72

6.53 Tolerance

The distance between axes which shall cut each other is given as follows when it is not important that axis 1 pass before or behind axis 2:

distance of axis 1 to axis 2: ± ... µm or mm (± ... in).

In other cases, when the tolerance depends on operating conditions it is stated as:

only when axis 1 is to be higher than axis 2 by ... µm or mm (... in).

Annex

Checking instruments for testing machine tools

A.1 General

This annex deals only with the instruments used for testing machine tools. Only those characteristics are given which are necessary to ensure the required accuracy of measurement in these instruments.

In general, for the characteristics of the test instruments, reference should be made to International Standards drawn up by Technical Committee ISO/TC 3, *Limits and fits*, and in particular cases to the national standards used in each country.

In the machine-tool industry there are three categories of measuring equipment, which differ solely in the accuracy to which they are made in order to fulfil the following functions:

- category A: reference standards for use in standard rooms;
- category B: measuring equipment for inspection purposes;
- category C: measuring equipment for use during manufacture.

This annex is concerned only with equipment of category B, i.e. measuring equipment used for examining machine tools after assembly.

A.2 Straightedges

A.21 Description

A straightedge is a material representation, to a given accuracy, of a straight reference line, by reference to which departures from straightness or flatness of a surface may be determined.

There are two principal types of straightedge:

- the bow-shaped straightedge [see figure 73a)] with a single edge;
- the straightedge with two parallel faces.

The latter type may be

of plain rectangular section [see figure 73c)];

I-section with a solid or lightened web [see figure 73b)].

Straightedges should preferably be heat-treated and stabilized.

A.22 Accuracy

For testing machine tools, straightedges shall comply with the following conditions.

A.221 Value of permissible deflection

The moments of inertia of the sections shall be such that the natural deflection of the straightedge, when resting on two supports situated at the extreme ends, shall not exceed 10 µm/m (0.000 12 in/foot).

The exact value of this natural deflection, which represents the maximum deflection of the straightedge, shall be marked on one of its faces.

A.222 Flatness and straightness of working faces

The errors in flatness and straightness of the working faces of straightedges when supported at the most favourable positions (see figure 73) shall not exceed the following amounts:

$(2 + 10L)$ micrometres
where L is the working length in metres

$(0.000\,1 + 10^{-5}L)$ inches
where L is the working length in inches.

In addition, the errors over any length of 300 mm should not exceed 5 µm, i.e. 0.000 2 in over any 12 in.

Examples are given in table 1.

A.223 Parallelism of working faces

For straightedges with two parallel faces, the error in parallelism of the working faces shall not exceed 1,5 times the tolerance on their straightness, viz.:

$1{,}5\ (2 + 10L)$ micrometres or $1.5\ (0.000\,1 + 10^{-5}L)$ inches.

A.224 Straightness of side faces

$10\ (2 + 10L)$ micrometres or $10\ (0.000\,1 + 10^{-5}L)$ inches.

A.225 Parallelism of side faces

$15\ (2 + 10L)$ micrometres or $15\ (0.000\,1 + 10^{-5}L)$ inches.

A.226 Squareness of side faces to working faces

± 2,5 micrometres per 10 mm or ± 0.000 25 in per inch depth of straightedge.

A.227 Surface finish of working faces

The working surfaces used when measuring should be either fine-ground or well scraped.

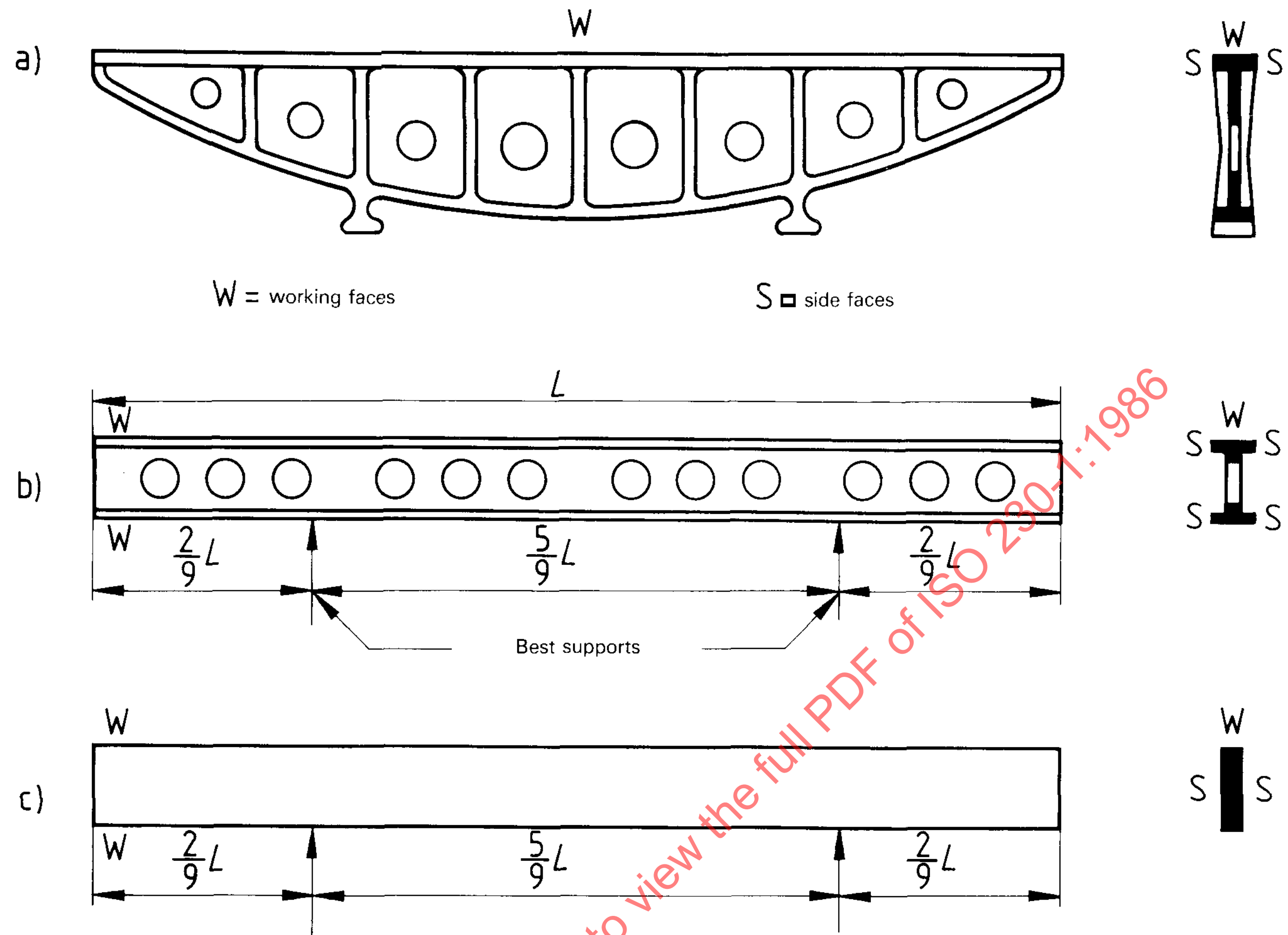


Figure 73

Table 1 — Examples

Working length L	300 mm (12 in)	500 mm (20 in)	800 mm (32 in)	1 000 mm (40 in)	1 600 mm (64 in)
Tolerance on straightness over whole length	5 µm (0.000 2 in)	7 µm (0.000 3 in)	10 µm (0.000 4 in)	12 µm (0.000 5 in)	18 µm (0.000 7 in)
Local tolerance over any length of 12 in (300 mm)	— —	5 µm (0.000 2 in)	5 µm (0.000 2 in)	5 µm (0.000 2 in)	5 µm (0.000 2 in)

A.228 Width of the straightedge

When the straightedge is used with a level, the width of the working faces shall be not less than 35 mm or 1 3/8 in.

A.23 Precautions in use

Straightedges are generally used horizontally, either resting on one of their side faces with their working faces vertical, or resting on supports with their working faces horizontal.

In the latter case, the supporting positions should be chosen preferably so as to reduce the natural deflection to a minimum. In the case of straightedges of a uniform section, the supports should be separated by $5L/9$, and situated at a distance of $2L/9$ from the ends (see figure 73). *These particular positions for the supports shall be clearly marked on the straightedge.*

When a straightedge is not resting on its best supports and, particularly, is supported at the extreme ends, *account should be taken of the natural deflection.*

Tables 2 (metric dimensions) and 3 (inch dimensions) show, as examples only, five straightedges of various lengths which would conform to these conditions. The natural deflection depends directly upon the modulus of elasticity E of the material used. The values of the deflection given in the tables correspond to straightedges made of ordinary cast iron : E = 10 000 kgf/mm^2 or 14 × 10^6 lbf/in^2. For steel E = 20 000 kgf/mm^2 or 28 × 10^6 lbf/in^2, the deflections would be halved. In the case of high-duty cast iron, where, for example E = 15 000 kgf/mm^2 or 21 × 10^6 lbf/in^2, the deflection would be proportional to the modulus of elasticity.