# INTERNATIONAL STANDARD

**ISO
230-1**

Second edition
1996-07-01

# Test code for machine tools —

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

*Code d'essai des machines-outils —*

*Partie 1: Précision géométrique des machines fonctionnant à vide ou dans des conditions de finition*

# Contents

# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 230-1 was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal-cutting machine tools*.

This second edition cancels and replaces the first edition (ISO 230-1:1986), which has been technically revised.

ISO 230 consists of the following parts, under the general title *Test code for machine tools*:

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

— *Part 2: Determination of accuracy and repeatability of positioning of numerically controlled machine tool axes*

— *Part 3: Evaluation of thermal effects*

— *Part 4: Circular tests for numerically controlled machine tools*

— *Part 5: Determination of noise emission*

Annexes A and B of this part of ISO 230 are for information only.

# Introduction

After general considerations on definitions, test methods, use of measuring instruments and tolerances, this part of ISO 230 deals more thoroughly with preliminary operations, geometric and machining tests, and special tests.

Annex A provides additional information about the instruments and equipment used in these tests.

Geometric tests consist of the verification of dimensions, forms and positions of components and 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 and of flat surfaces). They address only the sizes, forms, positions and relative movements which may affect the accuracy of the machine operation.

Practical tests consist of the machining of test pieces appropriate to the fundamental purposes for which the machine has been designed, and having predetermined limits and tolerances.

The clause numbering of the first edition ISO 230-1:1986 has been retained as far as possible. Clause numbering is changed only in 5.2 and 5.3 and former numbers are shown in parentheses at the corresponding entry of the contents list.

# Test code for machine tools —

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

## 1 Scope

The aim of this part of ISO 230 is to standardize methods of testing the accuracy of machine tools, operating either under no-load or under finishing conditions, by means of geometric and machining tests. The methods may also be applied to other types of industrial machines where geometric and machining tests are concerned.

This part of ISO 230 covers power-driven machines, 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 relates only to the testing of geometric accuracy. In particular, it deals neither with the operational testing of the machine tool (vibrations, stick-slip motion of components, etc.) nor with the checking of characteristics (speeds, feeds), as these checks should normally be carried out before testing of the accuracy of the machine tool.

When a measurement method not described in this standard can be shown to offer equivalent or better facilities for measuring the attributes to be studied, such a method may be used.

## 2 General considerations

### 2.1 Definitions relating to geometric tests

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

Geometric definitions are abstract and relate only to imaginary lines and surfaces. From this it follows that geometric definitions sometimes cannot be applied in practice. They take no account of the realities of construction or the practicality of geometric verification.

Metrological definitions are real, as they take account of real lines and surfaces accessible to measurement. They cover in a single result all micro- and macro-geometric deviations. They allow a result to be reached covering all causes of error, without distinguishing among them. Such distinction should be left to the manufacturers.

Nevertheless, in some cases, geometric definitions [e.g. definitions of run-out (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. However, when describing test methods, measuring instruments and tolerances, metrological definitions are taken as a basis.

### 2.2 Test methods and use of measuring 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 deviation can 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 tolerance are not exceeded.

It should be emphasized that inaccuracies 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 cause any error of measurement exceeding a given fraction of the tolerance to be verified. Since the accuracy of the devices used varies from one laboratory to another, a calibration sheet should be available for each instrument.

Machines under test and instrumentation 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 temperature variation.

A given measurement 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 sought either in the method or the measuring instrument, or in the machine tool itself.

For more precise indications, see annex A.

## 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 and 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) or as tangent (millimetres per millimetres).

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 narrower for large ranges than those which would result from the application of this law.

#### 2.312  Rules concerning tolerances

Tolerances include inaccuracies inherent in the measuring instruments and test methods used. Inaccuracies of measurement should consequently be taken into account in the permitted tolerances (see 2.2).

EXAMPLE

Tolerance of run-out: $x$ mm

Inaccuracy of instruments, errors of measurement: $y$ mm

Maximum permissible difference in the readings during the test: $(x - y)$ mm

Errors due to inaccuracies arising from comparative laboratory measurements, inaccuracies of form of machine parts used as reference surfaces, including surfaces masked by styli or by support points of measuring instruments, should be considered.

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

Lines or surfaces chosen as reference basis 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 2.324.

### 2.32  Subdivisions of tolerances

#### 2.321  Tolerances applicable to test pieces and to individual components of machine tools

It should be noted that the rules for indicating geometric tolerances on drawings given in ISO 1101 apply to the geometric accuracy of individual parts. These rules should be adhered to on manufacturing drawings.

##### 2.321.1  Tolerances of dimension

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

Deviations should be indicated numerically or by the symbols given in ISO 286-1.

EXAMPLE

$$80 \, {}^{+0,012}_{-0,007} \text{ or } 80\text{j}6$$

### 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 a thread or a gear tooth). They shall be expressed in units of length or of angle. Because of the dimensions of the stylus 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 stylus or support shall be stated.

The stylus surface and shape should be suitable for the microgeometry of the surface to be measured (a surface plate and the table of a heavy planing machine are not measured with the same stylus 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, perpendicularity, alignment, etc.). They are 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 1  When a position is determined in relation to surfaces showing errors of form, these errors should be taken into account when fixing the tolerance of position.

### 2.321.4 Influence of errors of form in determining positional errors

When relative 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 errors of form of lines and of surfaces, of which the relative positions are to be determined.)

When displayed in a graph (see figure 1) the different readings mn of the measuring instrument result in a curve, such as ab. It is to be accepted, as a rule, that

the error be determined using line AB instead of this curve, as stated in 5.211.1.
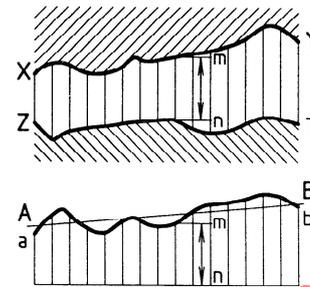


**Figure 1**

### 2.321.5 Local tolerances

Tolerances of form and position are usually related to the form or position as a whole (e.g. 0,03 per 1 000 for straightness or flatness). However, it may be desirable to limit the permissible deviation over a partial length to a different value. This is achieved by establishing a local tolerance related to a portion of the total length.

The local deviation is the distance between two lines parallel to the general direction of the part of the line or trajectory of the component which contains the maximum deviations of the partial length (see figure 2).
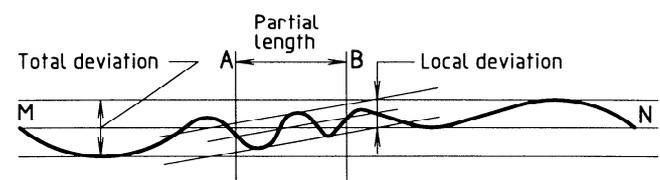


**Figure 2**

The value of the local tolerance ($T_{local}$) should be established:

— from the standard relating to a machine tool and for each particular test,

or

— as a proportion of the total tolerance ($T_{total}$), provided that it does not fall below a minimum value (normally 0,001 mm) (see figure 3).

In practice, local defects are generally imperceptible, as they are covered by the supporting or the detecting surfaces of the measuring instruments. However, when the detecting surfaces are relatively small (styli of dial gauges or micro-indicators), the measuring instrument should be such that the styli follow a sur-

face of high-grade finish (straightedge, test mandrel, etc.).
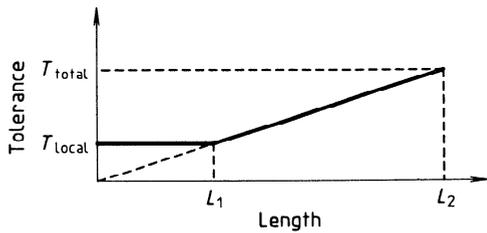


**Figure 3**

$$T_{local} = \frac{T_{total}}{L_2} \times L_1$$

EXAMPLE

$T_{total}$ = 0,03 mm
$L_2$ = 1 000 mm
$L_1$ = 100 mm

Then

$$T_{local} = \frac{0,03}{1\,000} \times 100$$
$$= 0,003 \text{ mm}$$

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

NOTE 2 Positioning accuracy and repeatability of numerically controlled machine tools shall be referred to ISO 230-2.

### 2.322.1 Tolerances of positioning

Tolerances of positioning limit the permissible deviation of the position reached by a point on the moving part from its target position after moving.

EXAMPLE 1 (see figure 4)

At the end of the travel of a slide, the deviation $d$ is the distance between the actual position reached and the target position. The tolerance of positioning is $p$.
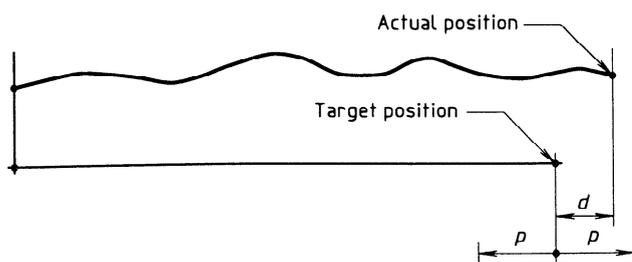


**Figure 4**

EXAMPLE 2

Angle of rotation of a spindle relative to the angular displacement of a dividing plate coupled to it (see figure 5). The tolerance of positioning is $p$.
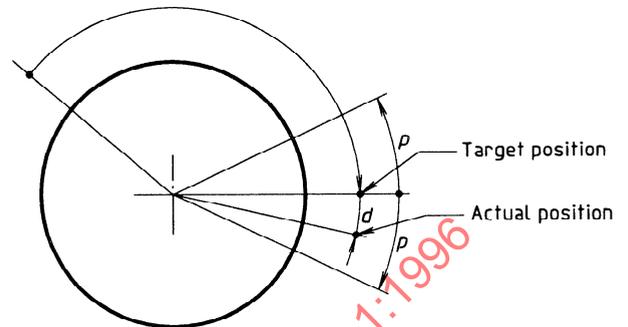


**Figure 5**

### 2.322.11 Tolerances of repeatability

Tolerances of repeatability limit the spread of deviations, when repeating movements approach the target in the same or opposite direction.

### 2.322.2 Tolerances of the form of trajectory

Tolerances of the form of trajectory limit the deviation of the actual trajectory of a point on the moving component relative to the theoretical trajectory (see figure 6). They shall be stated in units of length.
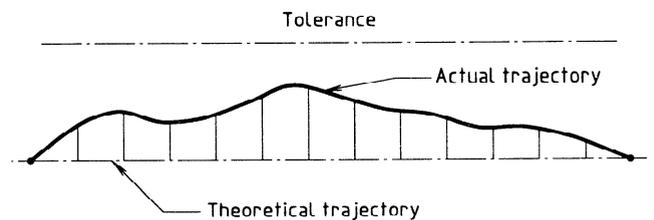


**Figure 6**
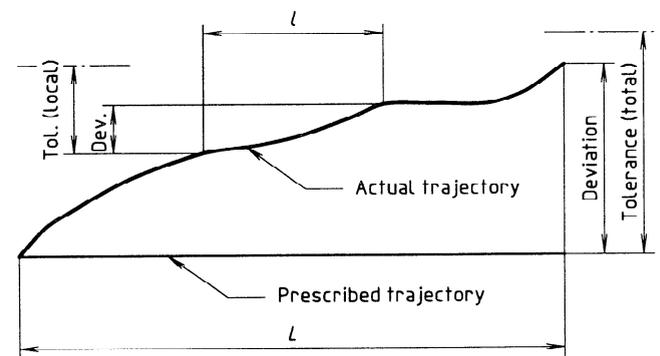


**Figure 7**

### 2.322.3 Tolerances of relative position of straight-line motion (see figure 7)

The tolerances of relative position of straight-line motion limit the permissible deviation between the

trajectory of a point of the moving component and the prescribed direction (for example deviation of parallelism or perpendicularity between the trajectory and a line or a surface). They are expressed in units of length for the total length $L$ or any measuring length of $l$.

### 2.322.4 Local tolerance of displacement of a component

Tolerances of positioning, form of the trajectory and direction of straight-line motion are also related to the total length of displacement of a component. When local tolerance is required, definition and establishment of the local tolerance value are similar to 2.321.5.

### 2.323 Overall or inclusive tolerances

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

EXAMPLE (see figure 8)

The deviation for the run-out of a shaft is the sum of the deviation of form (out-of-round of the circumference ab with which the stylus is in contact), the deviation of position (the geometric axis and the axis of rotation of the shaft do not coincide) and the deviation of out-of-round of the bore of the bearing.
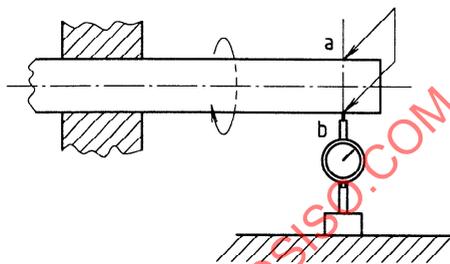


**Figure 8**

### 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.

### 2.325 Conventional definition of the axes and of the movements

In order to avoid using the terms transversal, longitudinal, etc., which are liable to create confusion, the axes of the displacements and rotations of the machine parts are designated by letters (e.g. X, Y, Z, etc.) and signs, in accordance with ISO 841.

## 3 Preliminary operations

### 3.1 Installation of the machine before test

Before proceeding to test a machine tool, it is essential to install the machine upon a suitable foundation 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) its levelling and is essentially determined by the particular machine concerned.

The aim of the levelling is to obtain a position of static stability of the machine which will facilitate subsequent measurements, especially those relative to the straightness of certain components.

### 3.2 Conditions 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 machine table in order to check the slideways).

### 3.22 Temperature conditions of certain components before test

The aim is to evaluate the accuracy of the machine under conditions as near as possible to those of normal functioning as regards lubrication and warm-up. During the geometric and practical tests, components such as 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.

Special conditions may be applied to high-precision machines and some numerically controlled machines for which temperature fluctuations have a marked effect on the accuracy.

It is necessary to consider how much the machine alters in dimensions during a normal working cycle from ambient to working temperature. The preliminary warm-up sequence and the ambient temperature at which the machine is to be tested should be the subject of agreement between the manufacturer and the user.

The main areas where thermal distortion can cause concern are:

a) the structure (including spindle) displacement, especially in the primary and axial planes;

b) the axis drives and positioning feedback systems which are important when the positioning accuracy depends on the lead screw.

### 3.23 Functioning and loading

Geometric tests 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 Machining tests

### 4.1 Testing

Machining tests shall be carried out on standard test pieces or test pieces supplied by the user. The execution of these machining tests shall not require operations other than those for which the machine has been built. Machining tests shall comprise the finishing operations for which the machine has been designed.

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 nominal accuracy. If necessary, wear on the cutting tool used should be taken into account.

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

### 4.2 Checking of workpieces in machining tests

Checking of workpieces in machining 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.

In certain cases, the machining tests may be replaced or supplemented by a special test defined in the corresponding International Standard (e.g. deflection test under load, kinematic test, etc.).

## 5 Geometric tests

### 5.1 General

For each geometric test of a given characteristic of shape, position or displacement of lines or surfaces of the machine such as:

— 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], methods of measurement and the way to determine the tolerance are given.

For each test at least one method of measurement is indicated, and only the principles and apparatus used are 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 elementary measuring instruments, such as straightedges, squares, mandrels, measuring cylinders, precision 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 components of large dimensions often requires the use of special devices for convenience and speed.

### 5.2 Straightness

Geometric checks covering straightness are the following:

— straightness of a line in a plane or in space, see 5.21;

— straightness of components, see 5.22;

— straightness of motion, see 5.23.

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1) See also 2.1.

## 5.21 Straightness of a line in a plane or in space

### 5.211 Definition

#### 5.211.1 Straightness of a line in a plane
(see figure 9)

A line located in a plane is deemed to be straight over a given length when all its points are contained between two straight lines parallel to the general direction of the line, whose relative distance is equal to the tolerance.

The general direction of the line or representative line shall be defined so as to minimize the straightness deviation. It may be conventionally defined either:

— by two points appropriately chosen near the ends of the line to be checked (in most cases parts close to the ends can be neglected, as they most often present insignificant local defects)

or

— by a straight line computed from plotted points (e.g. the least squares method).
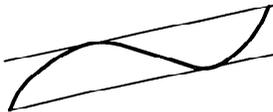


**Figure 9**

#### 5.211.2 Straightness of a line in space (see figure 10)

A line in space is deemed to be straight over a given length when each of its projections on two given perpendicular planes parallel to the general direction of the line is straight (see 5.211.1).



**Figure 10**

NOTE 3 The tolerance may be different in each plane.
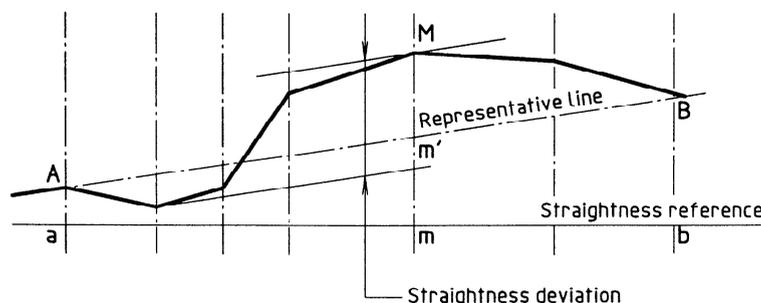
## 5.212 Methods of measurement of straightness

There are two methods for the measurement of straightness, based on either:

— the measurement of length

or

— the measurement of angles.

The practical reference for straightness can be physical (straightedge, taut-wire) or by comparison to reference lines given by a precision level, light beam, etc.

Recommended instruments:

a) for lengths below 1 600 mm: a precision level or physical reference (for example a straightedge);

b) for lengths above 1 600 mm: reference lines (a precision level, optical device or possibly a taut-wire).

### 5.212.1 Methods based on the measurement of length

A practical reference artifact (straightness reference) shall be placed in a suitable position relative to the line to be checked (see figure 11), to allow the use of a suitable measuring instrument.

The instrument provides deviation readings of the checked line with respect to the reference of straightness; readings may be obtained at various points (uniformly distributed or random) over the entire length of the checked line (selected point spacing being independent of the instruments used).

It is recommended to position the straightness reference in such a way that readings at both ends are approximately similar. Readings are then directly plotted using appropriate scales.

Results are processed by defining a representative line (see 5.211.1). Corrected deviations correspond to the values represented by Mm' segments.

The deviation of straightness is defined as the distance between two straight lines, parallel to the representative line, touching the upper and lower extremes of deviation.

NOTE 4 When the slope of the representative line is high, the vertical magnification should be considered.



**Figure 11**

7

### 5.212.11 Straightedge method

#### 5.212.111 Measurement in a vertical plane

The straightedge should be placed on two blocks, located, if possible, at the points corresponding to the minimum deflection due to gravity (for optimum support, see A.2).

The measurement shall be made by moving along the straightedge a dial gauge mounted on a support with three contact points. One of these contact points rests on the line of the surface to be measured and the dial gauge stylus is on the line normal to that contact point and in contact with the straightedge (see figure 12).

Provision shall be made for the moving component to follow a straight line (guiding straightedge).

Known errors of the straightedge can be taken into account, if required, in processing the result.

#### 5.212.112 Measurement in a horizontal plane

In this case it is advisable to use a parallel-faced straightedge lying flat.

The reference face is touched by a dial gauge moving in contact with the surface to be checked (see figure 13). The straightedge is set to give identical readings at both ends of the line; deviations in the line relative to the straight line joining the two extremes may be read off directly.
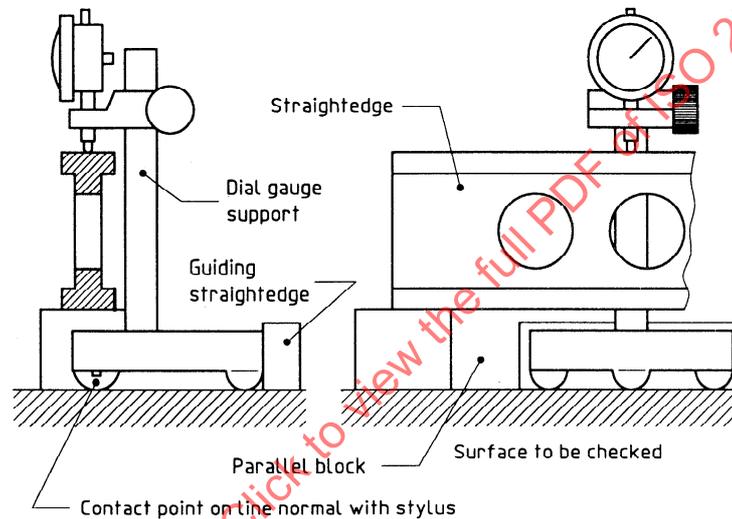


**Figure 12**
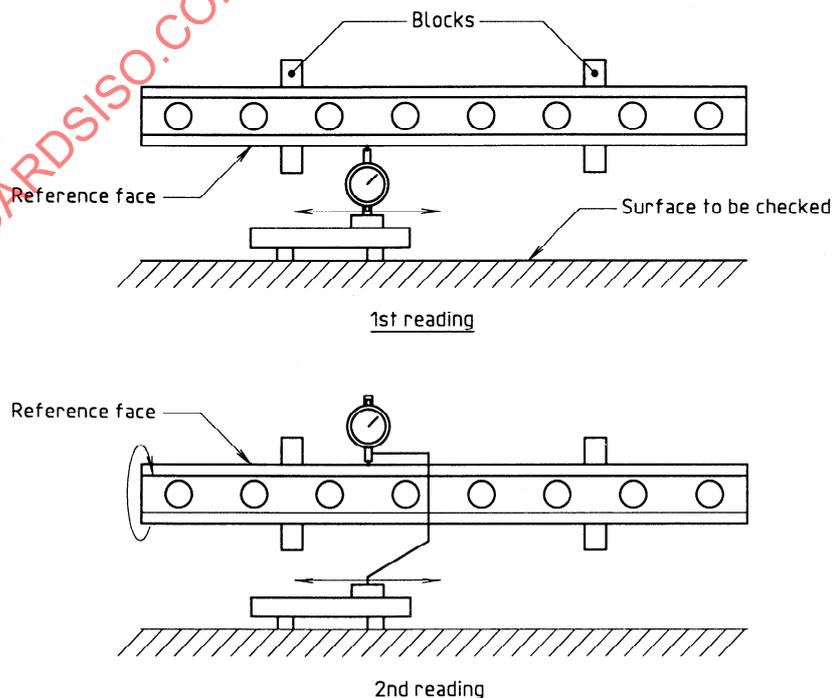


**Figure 13**

It should be noted that whatever the straightedge deflection on its supports, the reference-face straightness is in practice not altered by this deflection due to gravity.

Another feature of the straightedge method for straightness measurement in a horizontal plane is that it allows measurement of straightness deviations of both the straightedge reference face and the surface to be checked.

For this purpose the so-called reversal method is used. It consists, after a first measurement as described above, in rotating the straightedge 180° about its longitudinal axis and traversing the same reference face in reverse with the same dial gauge, also reversed and always resting on the surface to be checked.
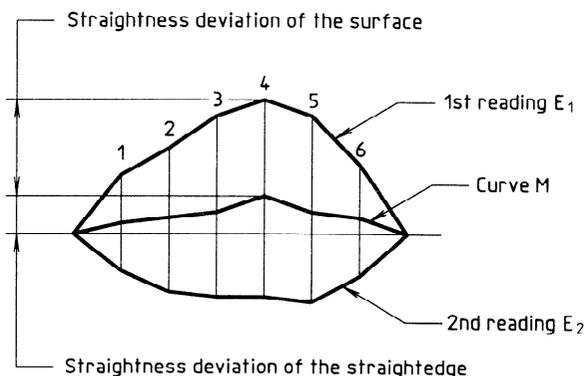


**Figure 14**

Both deviation curves $E_1$ and $E_2$ thus obtained and compared in figure 14 are the sum of the straightedge and surface deviations on the one hand, and the

difference between those deviations on the other hand.

The average curve M is the deviation of the reference face of the straightedge. Deviation $ME_1$ (or $ME_2$ which is equal) is the straightness deviation of the checked surface.

### 5.212.12 Taut-wire and microscope method

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 representing the reference of measurement in the horizontal plane of measurement XY (see also A.9).

The taut-wire F and the line to be checked shall be in the same plane perpendicular to the considered surface containing MN.

The microscope support rests on the surface containing the line to be checked at two points, of which one point P is situated in the plane normal to the surface considered, containing the microscope optical axis (see figure 15).

The taut-wire method is to be avoided when the sag $f$ of the wire F 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 of the wire is known at each point, but this sag is extremely difficult to determine with adequate accuracy.



Section according to X–Y plane
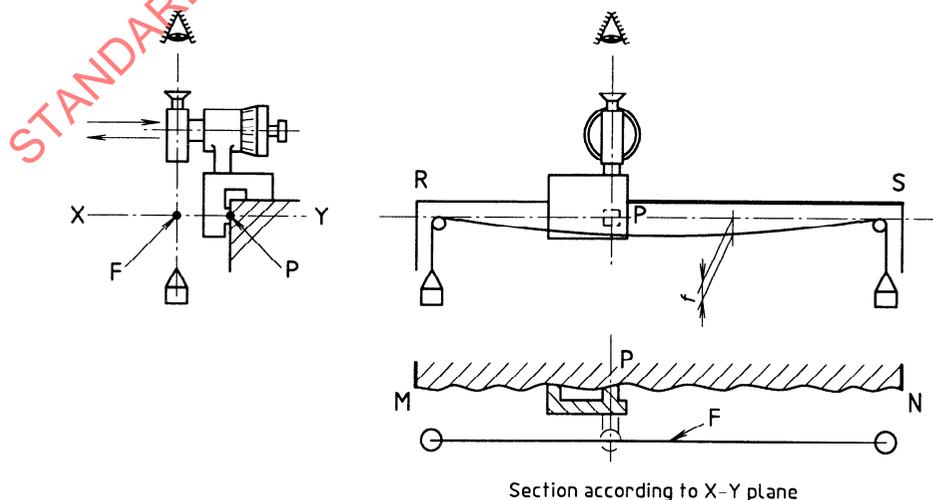
**Figure 15**

#### 5.212.13 Alignment telescope method

When using an alignment telescope (see figure 16), the difference in level, *a*, 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 (see A.10).

The optical axis of the telescope constitutes the reference of measurement.

By rotating the entire telescope and the target, it is possible to check the straightness of a line in any plane.

The target support should rest on the surface containing the line to be checked at as many points as required to ensure stability and guidance.

One of the target support points P shall be placed on the line to be checked and treated with all precautions as described in 5.212.12.

The target shall be normal to the surface containing the line to be checked at point P.

All precautions shall be taken for the moving element displacement to be reasonably rectilinear and parallel to the telescope optical axis.

In the case of longer lengths, the accuracy is affected by the variation of the refractive index of air, which contributes to the deviation of the light beam.

#### 5.212.14 Alignment laser technique (see figure 17)

A laser beam is used as the reference of measurement. The beam is directed at a four-quadrant photodiode detector which is moved along the axis of the laser beam. Horizontal and vertical deviations of the detector centre with respect to the beam are detected and passed to recording equipment. The measuring instrument manufacturer's instructions should be consulted (see also A.13).

Equal care shall be taken with one of the detector support points P as described in 5.212.13.

#### 5.212.15 Laser interferometry technique (see figure 18)

The bi-mirror reflector defines the reference of measurement.

A laser interferometer and special optical components are used to detect changes in the position of a target relative to the axis of symmetry of the bi-mirror reflector. The optical components and precise measuring methods vary and manufacturers' instructions should be consulted (see also A.13).

Equal care shall be taken with one of the detector support points P as described in 5.212.13.
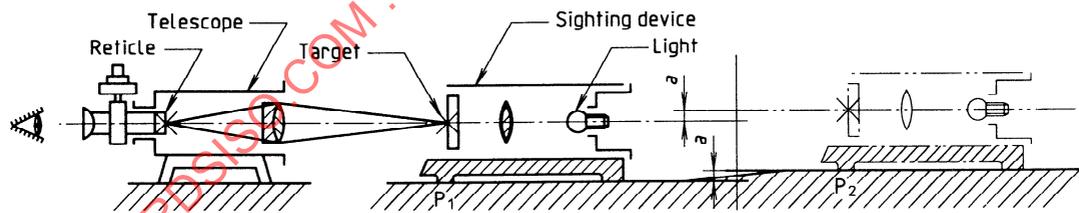


**Figure 16**
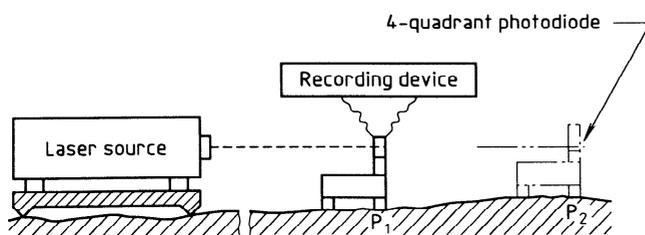


**Figure 17**
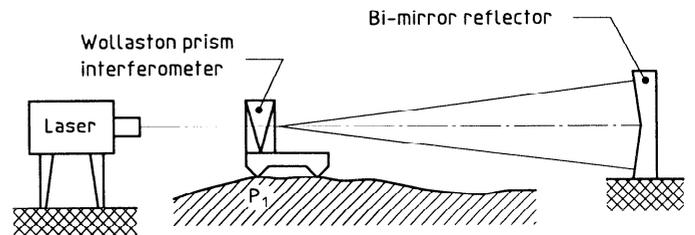


**Figure 18**

### 5.212.2 Methods based on the measurement of angles

In these methods a moving element is in contact with the line to be checked at two points P and Q separated by a distance $d$ (see figure 19). The moving element is displaced in such a way that in two successive positions $P_0Q_0$ and $P_1Q_1$, $P_1$ is coincident with $Q_0$. With an instrument placed in a plane perpendicular to the surface containing the line to be checked, the angles $\alpha_0$ and $\alpha_1$ of the moving element relative to a reference of measurement are measured.

NOTE 5   The part between the feet of moving elements is not checked by this method. This check can be carried out by a straightedge of appropriate length.



Reference of measurement
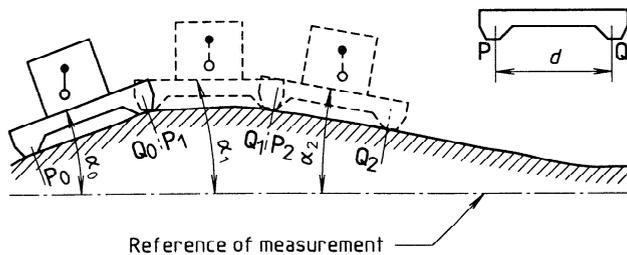
**Figure 19**

Results are processed as follows (see figure 20). The following parameters are plotted graphically with appropriate scales:

— in abscissae, the feet distances $d$ corresponding to the checking line,

— in ordinates, the relative differences of level with respect to the reference of measurement. The relative level difference is calculated as follows:

$$Eh_{i+1} = d \tan \alpha_i$$

The various points $P_0$, $P_1$, $P_2$ ... $P_i$ ... $P_n$ of the checked line can be located with the desired scale magnification.

The representative line is defined from the line itself, e.g. by the extremes $P_0 P_n$ (see 5.211.1).

The straightness deviation is defined as above (5.212.1) by the distance along the YY axis between two straight lines parallel to the representative line touching the curve at its higher and lower points.

NOTES

6   The supports P and Q of the moving element should be of sufficient area to minimize the effect of minor surface imperfections. It is necessary to prepare the supports very carefully and clean the surface in order to minimize deviations which can influence the overall curve.

7   These methods can also be applied over long distances but in this case the $d$ value should be chosen so that a large number of readings and cumulative errors can be avoided.

### 5.212.21   Precision level method

The measurement instrument is a precision level (see A.6) which is positioned successively along the line to be checked as explained in 5.212.2. The reference of measurement is the horizontal level of the instrument which measures small angles in the vertical plane (see figure 19).

If the line to be measured is not horizontal, the level is mounted on a suitably angled support block (see figure 21).
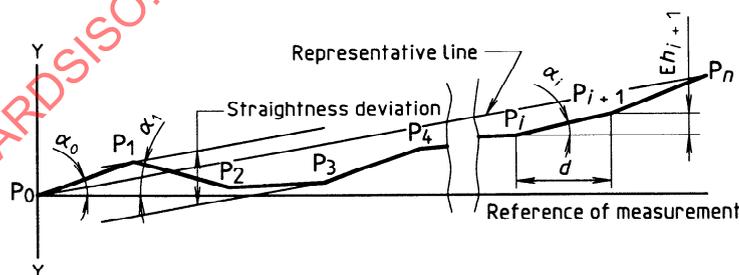


**Figure 20**
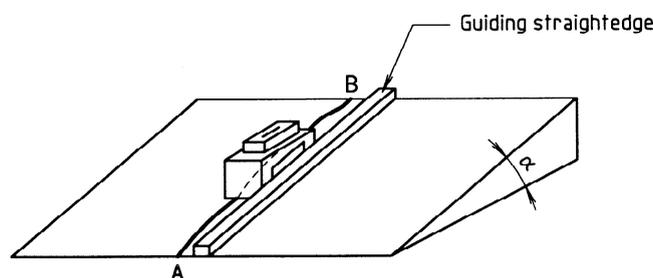


**Figure 21**

While checking line AB, the level together with its support should keep a constant orientation [e.g. by means of a guiding straightedge (see figure 21)].

NOTE 8   The level permits checking the straightness only in the vertical plane; for the checking of a line in a second plane another method should be used (e.g. taut-wire and microscope).

### 5.212.22   Autocollimation method

In this method, using an autocollimator mounted coaxially (see figure 22), 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 is made with the ocular micrometer, permits the angular deviation of the mirror holder to be determined (see also A.11).

The measuring reference is composed of the optical axis of the telescope as defined by the centre of the reticle.

NOTES

9   By rotating the ocular micrometer through 90°, the rotation angle of the movable mirror M around a vertical axis can also be measured. Instruments which are capable of measuring both angles simultaneously are available.

10   This method is especially suited to longer lengths because, in contrast to the alignment telescope, it is less influenced by variations in the index of refraction of air due to the double course of the light beam.

11   In this method, the autocollimator should preferably be mounted on the component on which the line is to be checked.

### 5.212.23   Method by laser interferometer (angle measurement) (see figure 23)

In this method the interferometer should be rigidly fixed to the same component on which the line is to be checked.

This method is especially suited to critical measurements because it is less influenced by variations in the index of refraction of the air.

The reference of measurement is constituted by two parallel beams $F_1$ and $F_2$ issuing from the interferometer.
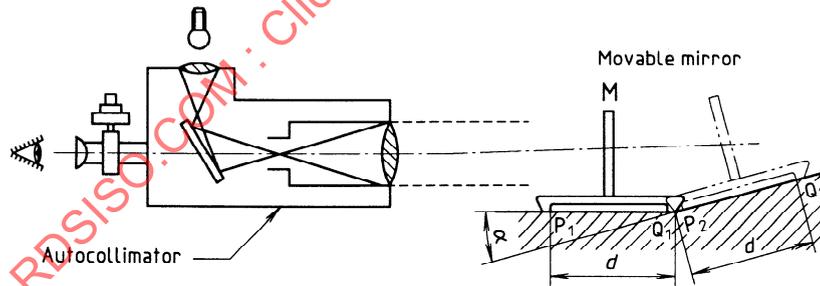


**Figure 22**
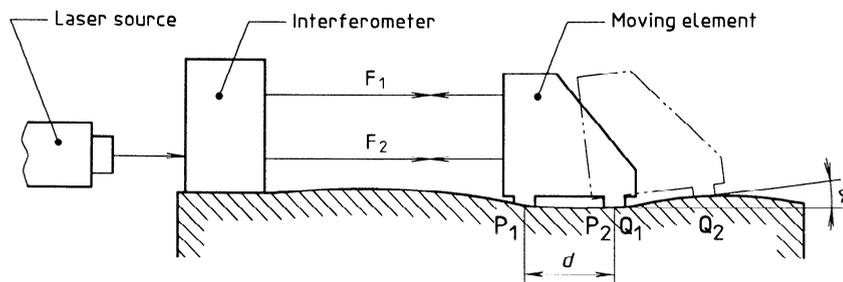


**Figure 23**

## 5.213  Tolerance

### 5.213.1  Definition

The tolerance $t$ is limited in the measuring plane by two straight lines separated by distance $t$ and parallel to the representative line AB (see figure 24). The maximum deviation indicated is MN.

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

In most cases, parts close to the ends, which usually have local deviations of no great importance, may be neglected.
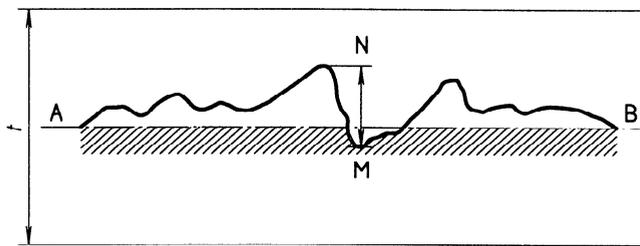


**Figure 24**

### 5.213.2  Determination of tolerance

A minimum tolerance $T_1$ is specified for any measuring length $L$ smaller than or equal to $L_1$ (see figure 25).

A maximum tolerance $T_2$ is specified for any measuring length $L$ greater than or equal to $L_2$.

For any intermediate measuring length (between $L_1$ and $L_2$) the tolerance $T_{(L)}$ is calculated by a proportional method:

$$L \leqslant L_1 \quad \rightarrow \quad T_{(L)} = T_1$$

$$L_1 < L < L_2 \quad \rightarrow \quad T_{(L)} = T_1 + \frac{T_2 - T_1}{L_2 - L_1}(L - L_1)$$

$$L \geqslant L_2 \quad \rightarrow \quad T_{(L)} = T_2$$
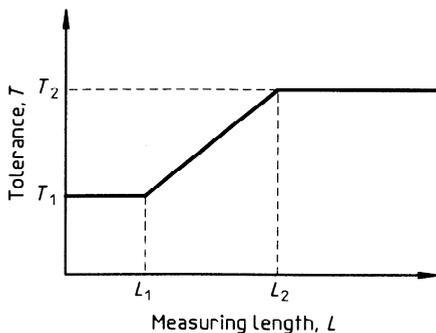


**Figure 25**

## 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).

### 5.222  Methods of straightness measurement

Measurement techniques are as for straightness of a line (see 5.212).

### 5.222.1  Reference grooves or reference surface of tables

In the case of a direct deviation measurement, the instrument shall read deviations in the normal plane of the line through the points P or Q with $h$ kept to a minimum (see figure 26).
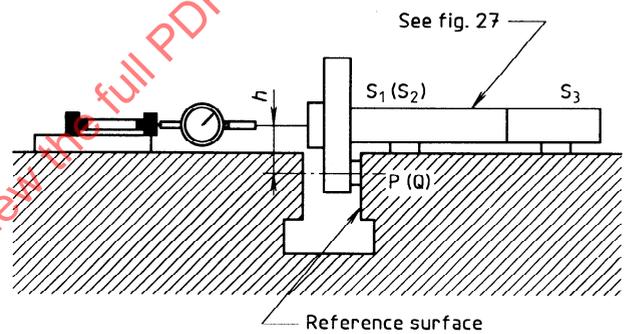


**Figure 26**

In the case of angular deviation measurements, the distance $d$ defines the measuring-point spacing (see figure 27).

The moving element shall lie flat on the table (resting preferably on three localized surfaces $S_1$, $S_2$, $S_3$) and include two functional bearing surfaces P and Q on the line to be checked (see figure 27).
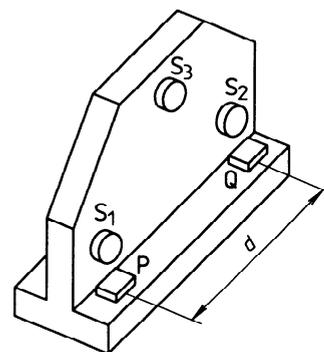


**Figure 27**

Straightness deviations of more complex reference surfaces (see figure 28) are measured in the functional planes of the slideway (lines HH and VV) and not square to the reference plane.
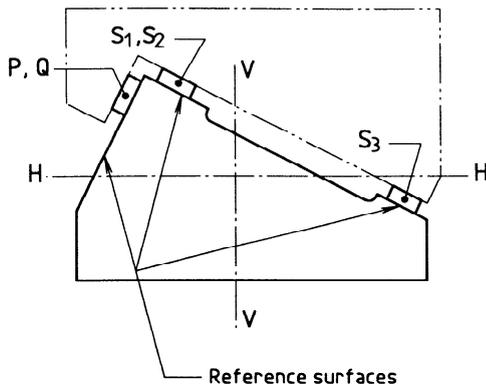


**Figure 28**

### 5.222.2  Slideways

Guiding is ensured by slideways or by more complex devices which cannot be dismantled without destroying the machine geometry. The checking of slideways involves the measurement of straightness and should only be carried out if the component is accessible. More complex slideways must be checked as part of the measurement of the straight-line motion of the moving component (see 5.23).

The deviation of straightness should always be checked in the functional plane. Generally, this can be regarded as either horizontal (figure 29 line AA) or vertical (figure 29 line BB) although exceptions may occur with certain machine configurations (see figure 36).

It must be noted that the longitudinal shape of a slideway is not necessarily straight, as it may present in the functional plane a special form specified by the manufacturer.

The guiding surfaces may be composed of the following:

a)  one plane or several small sections joined together;

b)  several narrow plane sections, cylindrical slideways or an assembly of the two.
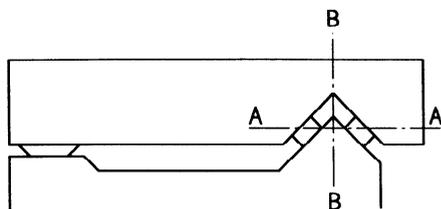


**Figure 29**

### 5.222.21  Vee surfaces

The moving body should bear on the surfaces at four contact points. It shall also be supported by an ad-

ditional point on a different surface of the slideway for stability.

Figures 30 and 31 show the use of a recessed cylinder, and figure 29 an inverted recessed vee.

NOTE 12  The additional support point should not exert a positioning force on the moving component.
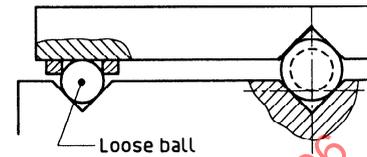


**Figure 30**
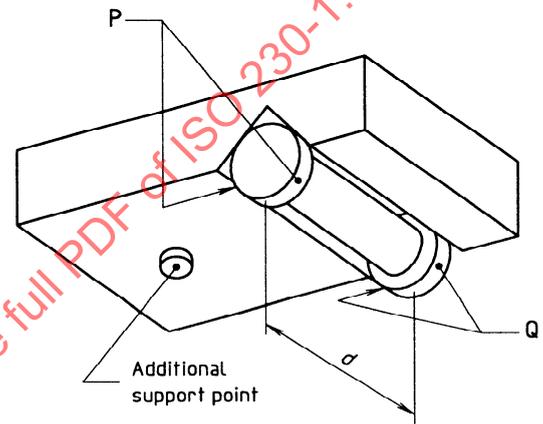


**Figure 31**

### 5.222.22  Cylindrical surfaces

The moving body on four pads should rest on the cylinder. This is in the form of an inverted vee (see figures 32 and 33).

The same precaution shall be taken as above regarding the additional support of the block.
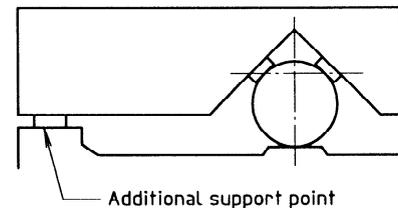


**Figure 32**



**Figure 33**

**14**
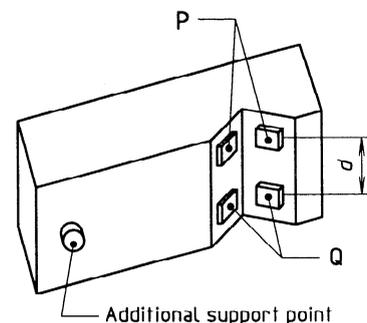
### 5.222.23 Single vertical surfaces

The moving body makes contact by two points, P and Q, on the surface to be measured. Three additional support points are required to guide the moving body. These should be chosen to ensure guiding without influencing the positioning of the two operational contact points (see figures 34 and 35).

NOTE 13  When the deviations are being measured directly, the instrument should take measurements on the plane normal to the surface and through one of the contact points, and when measuring angular deviations, the distance $d$ defines the measurement pitch.
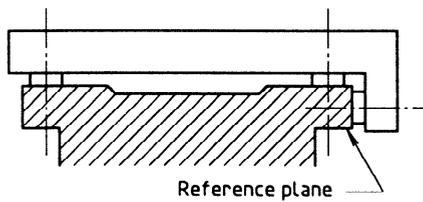


**Figure 34**
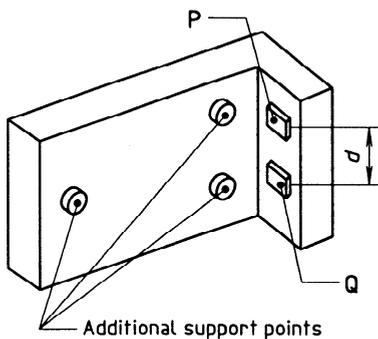


**Figure 35**

### 5.222.24 Slant-bed configuration (see figure 36)

In this case, the functional plane of the moving element is at an angle to the horizontal plane.

The deviation of straightness is measured in this functional plane (line AB) and a plane that is normal to it.
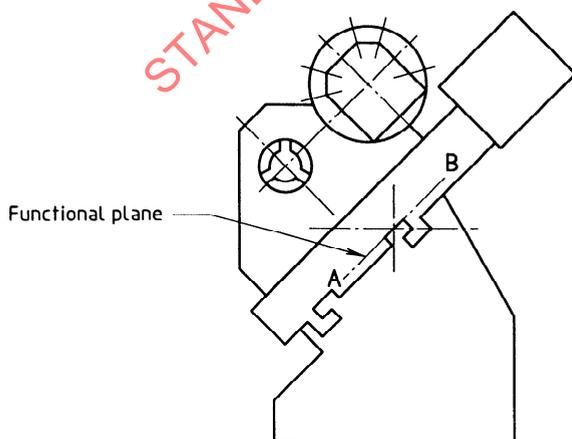


**Figure 36**

### 5.222.3 Tolerances

See 5.213.

## 5.23 Straight-line motion

Tests for the straight-line motion of a component of a machine tool are required not only to ensure that the machine will produce a straight or a flat workpiece but also because the position accuracy of a point on the workpiece is related to the straight-line motion.

### 5.231 Definitions (see figure 37)

The straight-line motion of a moving component always involves six elements of deviation:

a)  one positional deviation in the direction of motion;

b)  two linear deviations of the trajectory of a point on the moving component;

c)  three angular deviations of a moving component.
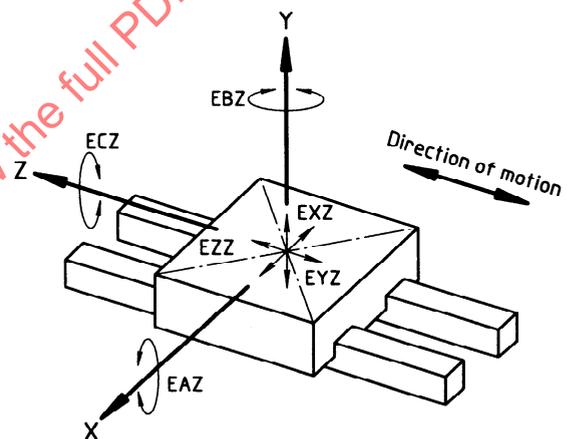


Deviation by Z-direction motion

| | | | |
|---|---|---|---|
| EXZ: Linear deviation | EAZ: Pitch | } | Angular deviation |
| EYZ: Linear deviation | EBZ: Yaw | | |
| EZZ: Positional deviation | ECZ: Roll | } | |

**Figure 37**

### 5.231.1 Positional deviations

Positional deviations are dealt with in 2.322.1 and ISO 230-2.

### 5.231.2 Linear deviations

Linear deviation of straight-line motion is defined by the straightness of the trajectory of the functional point or the representative point of a moving component. The functional point is the position of the tool when a moving component carries the tool. When a moving component carries the workpiece, the centre of the table may be regarded as the representative point.

### 5.231.3 Angular deviations

Whenever a component is moved, it is involved in angular deviations. These angular deviations are called roll, pitch and yaw, as shown in figure 37.

All of these deviations will affect straight-line motion. When measuring the straight-line motion of the trajectory of a representative point, the measured results include all of the effects of angular deviations, but the effects of these angular deviations are different when the position of a point of the moving component is different from the representative point, and a separate measurement must be made. The value of each angular deviation is the maximum angle turned through during a complete traverse of the moving component.

### 5.232 Methods of measurement

### 5.232.1 Methods of measurement of linear deviations

To plot the trajectory of a functional point of a moving component, the following methods are used.

### 5.232.11 Method with a straightedge and a dial gauge (see 5.212.112)

When using a straightedge and a dial gauge, it is usual to fix the straightedge to the component used as a reference (work tables of milling machines, machining centres, grinding machines, the bed of a lathe, etc.). The dial gauge is connected to the tool location point with its stylus situated as near as possible to the active zone of the tool (see A.2 and A.7).

### 5.232.12 Method with microscope and taut-wire (see 5.212.12)

This is the same situation as a straightedge and dial gauge, with the taut-wire representing the straightedge and the microscope representing the dial gauge (see A.9).

### 5.232.13 Method using an alignment telescope (see 5.212.13)

When using an alignment telescope, the reticle is connected to the reference line, the target is connected to the tool post and its centre is situated as near to the active zone of the tool as possible (see A.10).

### 5.232.14 Method using a laser (see 5.212.14 and 5.212.15)

When using a laser (direct measurement using a straightness interferometer), the devices defining the measuring reference must be firmly fixed to the component chosen as reference. The moving element is fixed to the tool holder and its centre is situated as near as possible to the active zone of the tool (see A.13).

### 5.232.15 Method using angle measurements (see 5.212.2 and 5.232.2)

This method is not recommended for the checking of linear deviations. For checking slideway straightness, the moving element has two feet, P and Q, which are $d$ apart (see figure 19) and the slideway is checked successively in increments of $d$.

In this case, the moving component, in general, has no such feet and contacts the surface over its full length.

The results obtained may be somewhat different from the true trajectory. Assuming the surface is smooth and the moving component moves as the envelope of the surface, linear deviation can be assumed by the process shown in figure 38.

At the $i$th measuring point, the angular deviation is $\theta_i$. Assume $\theta_i$ is effective from the midpoint of $i-1$ and $i$ to $i$ and $i + 1$. When an apparent change in $\theta$ occurs, the distance of measurement shall be changed there.

### 5.232.2 Methods of measurement of angular deviation

When the movement is in a horizontal plane, a precision level can measure the pitch and roll, whereas an autocollimator and laser can measure the pitch and yaw.
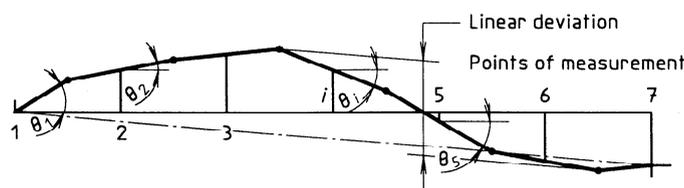


**Figure 38**

### 5.232.21 Method using a precision level (see 5.212.2)

When using a precision level, the instrument is fixed to the moving component. The component is moved incrementally and the level readings are recorded after each move.

### 5.232.22 Method using an autocollimator (see 5.212.22)

When using an autocollimator, the mirror is mounted on the moving component and the autocollimator on the reference line.

### 5.232.23 Method using a laser (see 5.212.23)

When using a laser, the remote interferometer and beam bender can be fixed on the reference line and the laser reflectors mounted on the moving component or vice versa.

### 5.233 Tolerance

#### 5.233.1 Tolerance for the linear deviation of straight-line motion

Tolerance defines the permissible deviation of the straight-line motion of the trajectory of a functional or representative point in relation to the representative line (general direction of the trajectory); the tolerances of the two linear deviations may be different.

#### 5.233.2 Tolerance for the angular deviation of straight-line motion

Tolerance defines the permissible angular deviation of the straight-line motion of the component.

Tolerance of angular deviation may be different for the three components of pitch, roll and yaw.

## 5.3 Flatness

### 5.31 Definition

A surface is deemed to be flat within a given range of measurement when all the points are contained within two planes parallel to the general direction of the plane and separated by a given value.

The general direction of the plane or representative plane is defined so as to minimize the flatness deviation, i.e., conventionally, either:

— by three points conveniently chosen in the plane to be tested (usually the part very near to the edge, having minor local defects, can be disregarded)

or

— on a plane calculated from the plotted points by the least squares method.

## 5.32 Methods of measurement

### 5.321 Measurement 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 applied only to smaller-sized surfaces which present a relatively fine finish (scraped or ground surfaces).

### 5.321.1 Measurement by means of a surface plate and a dial gauge

The measuring equipment consists of a surface plate and a dial gauge held in a support with a ground base which moves on the surface plate.

There are two measuring configurations:

a) the component to be measured is placed on the surface plate (the dimensions of the surface plate and the shape of the dial gauge support must be large enough to enable all the surface to be measured) (see figure 39).
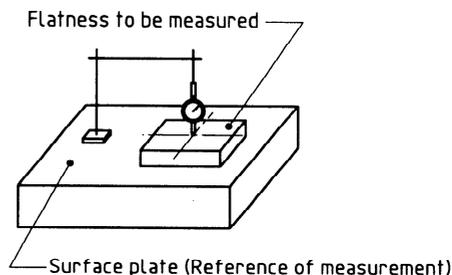


Figure 39

b) the surface plate is placed facing the surface to be measured. In this case, testing is possible with a surface plate whose dimensions are similar to that of the surface to be measured (see figure 40).



Figure 40

A pattern of squares is established to determine the locations of the measuring points.

False readings due to surface defects may be avoided by:

a) using a dial gauge with a slightly rounded stylus which is not affected by roughness;

b) placing a small ground block with parallel faces between the surface to be measured and the stylus of the dial gauge to absorb the surface defects (scraped surfaces, planed surfaces, etc.).

NOTE 14   In the first arrangement (figure 39) the position of the dial gauge is influenced by the variation in the slope on the surface of the surface 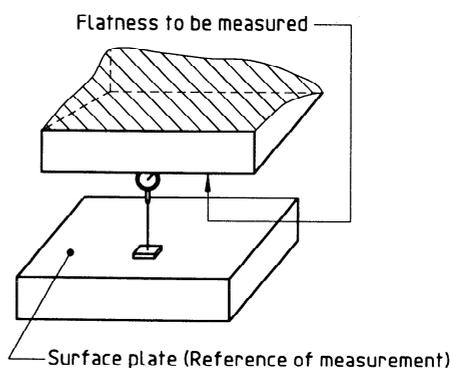plate. This method should be reserved for highly accurate surface plates. It is not possible to take into account the defects of the surface plate; this method is reserved for small parts.

In the second arrangement (figure 40), where measurement is carried out by a dial gauge holder set perpendicularly to the surface plate, it is possible to take into account the defects of the surface plate while processing the results.

### 5.322   Measurement of flatness by means of straightedge(s)

#### 5.322.1   Measurement 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, three points, a, b and c, on the surface to be tested are selected as zero marks (see figure 41). 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.
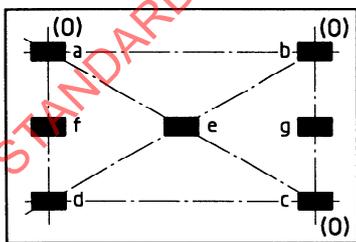


**Figure 41**

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 deviation of point d is then found by placing the straightedge on points b and e; an adjustable block is placed at point d and its upper face 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 deviations of all the intermediate points on the surface lying between a and d and between b and c may be found. The deviations 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.)

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 deviations 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 and the straightedge can be measured. It is possible to use an instrument for the measurement of straightness, as shown for example in figure 12.

#### 5.322.2   Measurement by means of straightedges, a precision level and a dial gauge (see figure 42)

In this method the reference of measurement is provided by two straightedges which are placed parallel by means of a precision level (see A.6).

Two straightedges $R_1$ and $R_2$, mounted on rests a, b, c, d of which three are the same height and one is adjustable, are set up so that their upper rectilinear surfaces are parallel by using a precision level. The two straight lines $R_1$ and $R_2$ are thus coplanar. One reference straightedge R placed on $R_1$ and $R_2$ on top of any line fg of the square pattern enables the deviations to be read by means of a reading instrument G (or by means of standard gauge blocks).

The straightedges $R_1$ and $R_2$ shall be sufficiently rigid so that the deflection due to the weight of the reference straightedge is negligible.
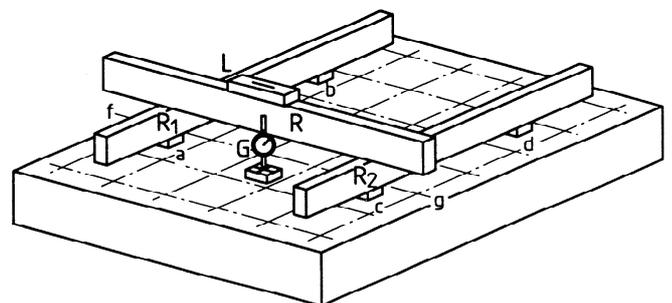


**Figure 42**

A reference of measurement is established and deviations from the reference of measurement are measured and plotted. Plotting may be carried out at different points following a regular pattern of squares,

see figure 43, covering all the surface of the plane to be measured. The choice for spacing the points is independent of the instruments used.
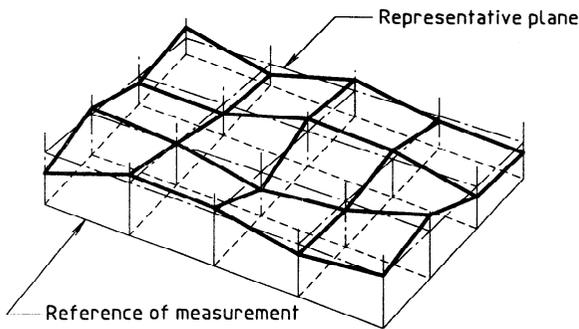


**Figure 43**

### 5.323 Measurement of flatness by means of a precision level

This is the only method known at present which enables a constant direction of measuring reference (horizontal) to be maintained while the instrument is moved from position to position.

Straightness measurement of a line using the angular deviation method (5.212.2) is the basis of this measurement.

#### 5.323.1 Measurement of a rectangular surface

The reference plane is determined by two straight lines OmX and OO'Y, where O, m and O' are three points on the surface to be checked (see figure 44).
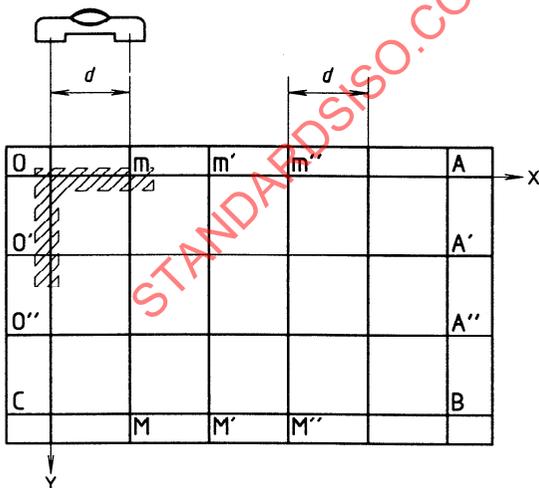


**Figure 44**

The lines OX and OY are chosen preferably at right angles and if possible parallel to the sides outlining the surface to be measured. Measurement begins in one of the corners O of the surface and in the direc-

tion OX. The profile for each line OA and OC is determined by the method indicated in 5.212.21. The profile of the longitudinal lines O'A', O" A" and CB is determined so as to cover the whole surface.

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

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

**Interpretation of measured results** (see figures 45 and 46).

From the results of measuring lines Omm'A and OO'O"C, using the process shown in figure 20, draw a topographical plotting of Omm'A and OO'O"C. For plotting of lines O'A', O"A" and CB the starting points shall be O', O" and C. In the case of figure 45, all the plottings are very near to the measuring reference and this plane may be said to be a representative plane, but in the case of figure 46 representative lines of Omm'A and OO'O"C are in the directions OX' and OY'. In such a case, the representative plane will probably be the plane containing OX' and OY', i.e. plane OABC.
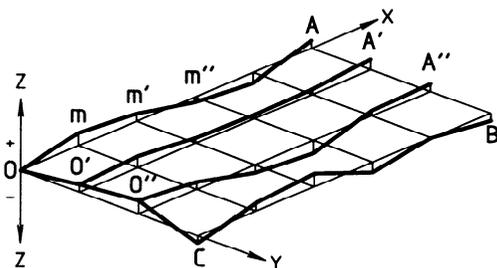


**Figure 45**
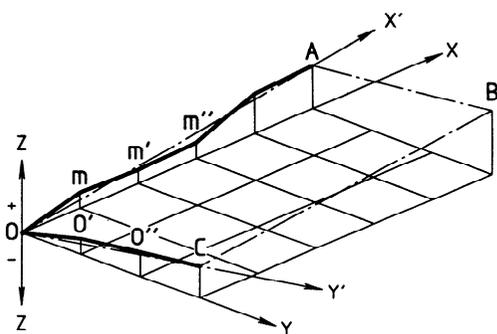


**Figure 46**

#### 5.323.2 Measurement of plane surfaces with circular contours

Large plane surfaces which have circular contours do not lend themselves to an orthogonal square pattern,

**19**

which leaves certain parts unchecked. Therefore, it is preferable to carry out the survey using peripheral circles and diameters (see figure 47).
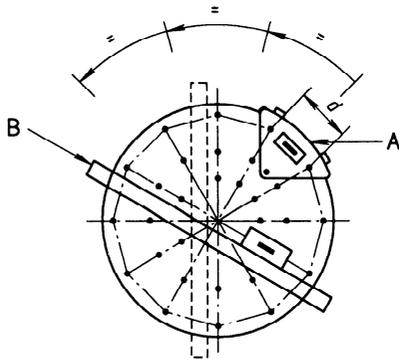


**Figure 47**

NOTE 15  For small surfaces, flatness measurements are carried out in a simplified way by measuring the straightness:

— of two perpendicular diameters;

— of the sides of the square joining extreme points (see figure 48).
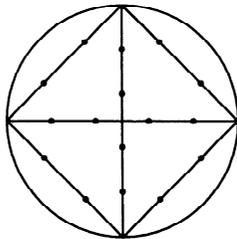


**Figure 48**

a)  Circular verification

A precision level is placed on an isostatic support A and moved at regular intervals around the periphery of the plate.

b)  Diametrical verification

This is carried out using any method of measuring the straightness of a line (see 5.21).

### 5.324  Measurement of flatness by optical methods

#### 5.324.1  Measurement by an autocollimator

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

The reference plane of measurement is determined by the directions of the optical axes of the autocollimator OX and OY. Thus, for the measurements of O'A', O"A" and CB, the optical axis of the autocollimator shall be parallel to OX (see figure 44).

#### 5.324.2  Measurement by a sweep optical square

Alternatively, a sweep optical square (pentagonal prism) is used. The reference plane is established by the centres of the three datum targets (A, B and C) placed at the periphery of the surface (see figure 49). The square is aligned so that the telescope optical axis is perpendicular to the reference plane and a fourth target is used to measure the position of any point on the surface (see A.12).



**Figure 49**

20
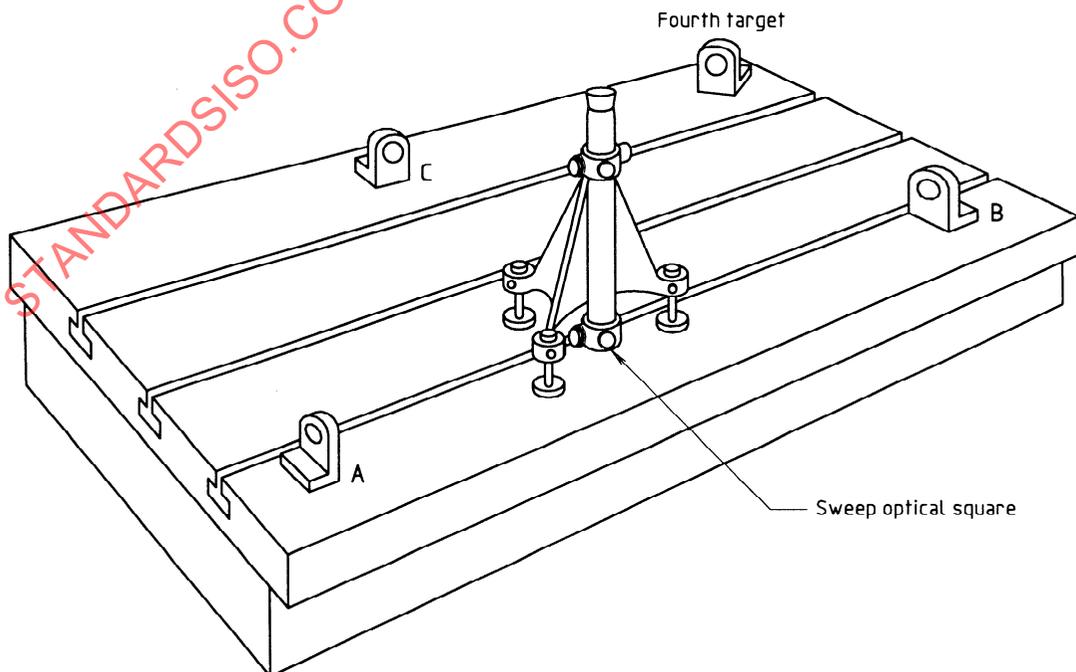
### 5.324.3 Measurement by an alignment laser

In this method, a scanning module is used in association with an alignment laser to define a plane of reference for the measurement with the aid of various coplanar rectilinear references (see figure 50 and A.13).

### 5.324.4 Measurement by a laser measuring system

The topography of a surface is reconstituted from the examination of the straightness of different lines by measuring angular deviations (see A.13).

A typical sequence of measurement is shown in figure 51, where lines 1 to 8 are illustrated diagramatically.

Successively, lines 1 to 8 are checked. The resulting readings analysed by data processing give a plot of surface-plate flatness in isometric form (see figure 52).

NOTE 16   The laser beam is horizontally adjusted in the desired direction by adjusting the turning mirror. This however may affect the vertical direction of the laser beam.
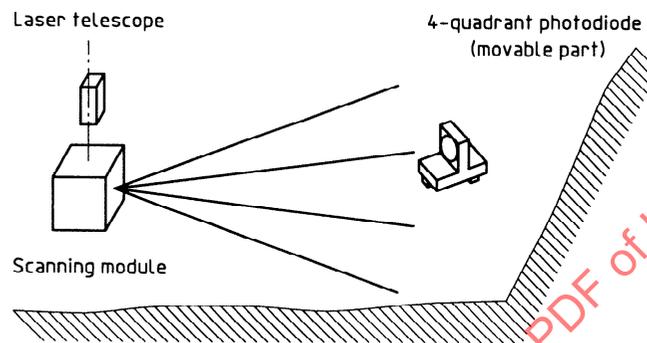


**Figure 50**
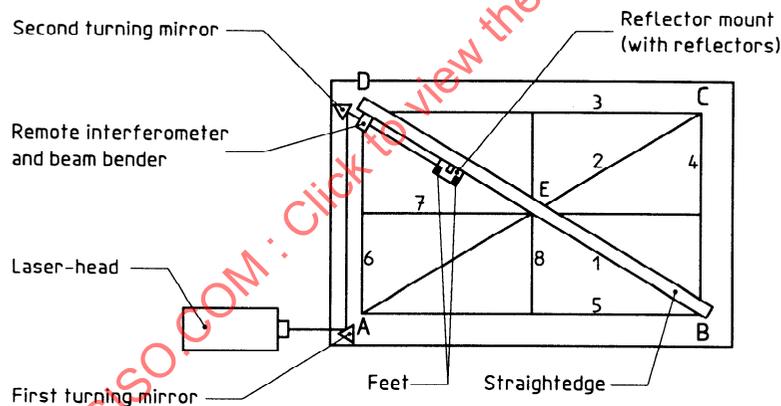


**Figure 51**
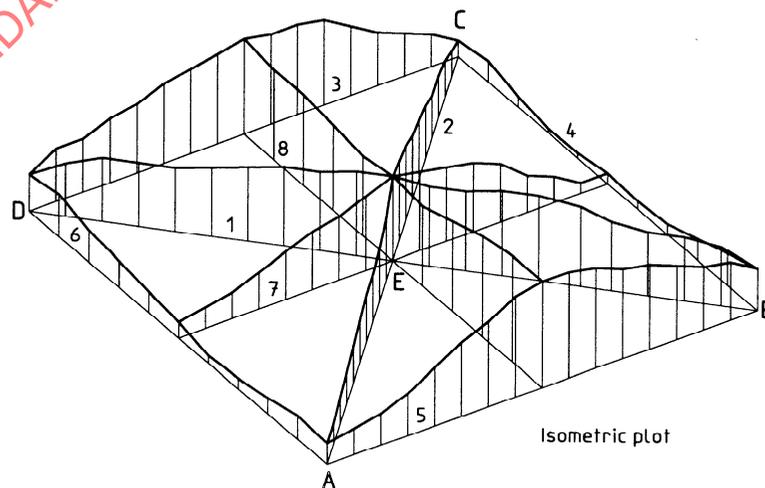


**Figure 52**

### 5.325 Measurement by a coordinate measuring machine

Surface flatness can be measured by a coordinate measuring machine (CMM). A reference plane may be established from the CMM software according to 5.31 and out-of-flatness from this plane is determined (see figure 43).

### 5.33 Tolerances

The tolerance zone of the flatness is limited by two planes, distant by $t$, parallel to the general direction of the plane (representative plane).

The range of measurement and the position of the tolerance in relation to the representative plane should be specified.

Tolerances of flatness are indicated as follows.

— Tolerance of flatness: . . . mm when, between the ends, concavities and convexities of surfaces are allowed.

— Concave (or convex) to: . . . mm when, between the ends, only concavities (or convexities) of surface are allowed.

— Local tolerance: . . . mm for . . . mm × . . . mm when it is specified and both concavities and convexities are allowed.

Further tolerance in this case should be known as "local tolerance".

NOTE 17   The results of the check may be affected by the condition of the contact surface of the instrument stylus. When deemed necessary, the condition of this contact surface may be specified.

## 5.4 Parallelism, equidistance and coincidence

These measurements address the following features:

— parallelism of lines and planes, see 5.41;

— parallelism of motion, see 5.42;

— equidistance, see 5.43;

— coaxiality, 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 representative line (see 5.211.1) of intersection of the plane and the normal plane including the line 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 representative line of the other line. The tolerances of parallelism are not necessarily identical in the two planes.

Two planes are deemed to be parallel when the maximum range of distances from the representative plane of one of these planes to the other plane, measured over the entire surface in at least two directions, does not exceed an agreed value over a specified length.

Maximum range 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 entire surface).

NOTE 18   Parallelism is defined as the difference of distance from the representative line (or plane) of a line (or plane) to another line or plane. If the line (or plane) selected as reference is inverted, the result may be different.

### 5.412 Methods of measurement

### 5.412.1 General, for axes

Where measurement 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 attachments.

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 53).
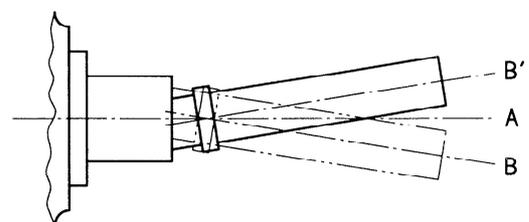


**Figure 53**

The measurement of parallelism may, under these conditions, be effected at any angular orientation of the spindle, but should be repeated after rotating the spindle through 180°. The algebraic mean of the two readings gives the deviation of parallelism in the given plane.

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

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

NOTE 19   The term 'mean position of run-out' is to be understood as follows: a gauge stylus is brought into contact, in the plane of test, 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 following methods can be used to verify the parallelism of two planes. The measurements should be carried out in two directions, preferably perpendicular to each other.

### 5.412.21   Straightedge and dial gauge

The dial gauge, mounted on a support with a flat base and guided by contact with the straightedge, is moved on one plane by the amount specified. The stylus slides along the second plane (see figure 54).



Guiding straightedge
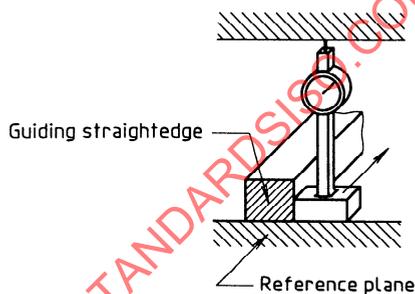
Reference plane

**Figure 54**

### 5.412.22   Precision level method

The level is supported on a carrier which bridges the two planes to be compared. A succession of readings is taken along the planes and then the maximum difference of reading (angle) gives the angular parallelism deviation and the reading (angle) multiplied by $l$ gives the linear parallelism deviation (see figure 55 and A.6).

If it is difficult to bridge the two planes, the carrier is not used and readings are taken along each plane with the horizontal used as the measuring reference (5.212.2). Comparison of the readings at corresponding positions indicates parallelism.



Guide block

Carrier

$l$
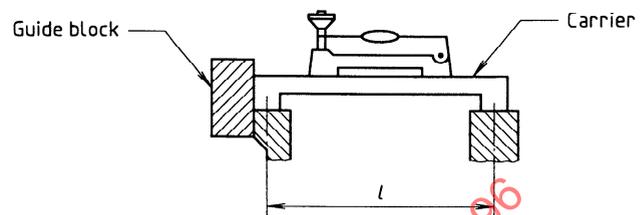
**Figure 55**

### 5.412.3   Parallelism of two axes

The measurement is made in two planes:

— in a plane passing through two axes[2];

— then in a second plane perpendicular, if possible, to the first.

### 5.412.31   Plane passing through two axes[2]

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 stylus slides along the cylinder representing the second axis.

To determine the minimum reading between the axes at any point, the instrument shall be gently rocked in a direction perpendicular to the axes (see figure 56). If necessary, the deflection of the cylinder under the weight it will have to support during measurement may be taken into consideration.
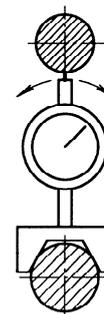


**Figure 56**

### 5.412.32   Second plane perpendicular to the first

This measurement method requires an additional plane, if possible parallel to that passing through the two axes.

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

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 measurement 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 zero. If the two axes are not in the same horizontal plane, an auxiliary block, fixed or adjustable, may be used (see figures 57 and 58).
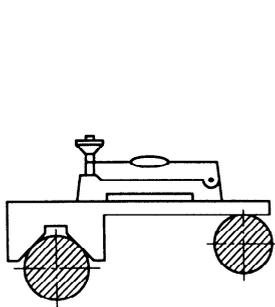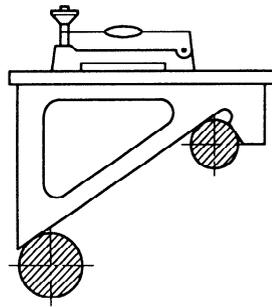


**Figure 57** **Figure 58**

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 and the level reading is 0,06 mm/1 000 mm, the deviation of parallelism will be 0,06 × 0,3 = 0,018 mm.

### 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 stylus will slide along the cylinder representing the axis (see figure 59).
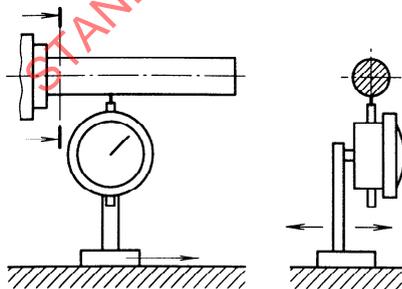


**Figure 59**

At each point of measurement, the minimum reading is found by slightly moving the measuring instrument in a direction perpendicular to the axis.

In the case of a pivoting axis, measurement in the mean position and the two extreme positions will be sufficient (see figure 60).

NOTE 20 For the deviation of parallelism of the representative cylinder from the axis, see 5.412.1.
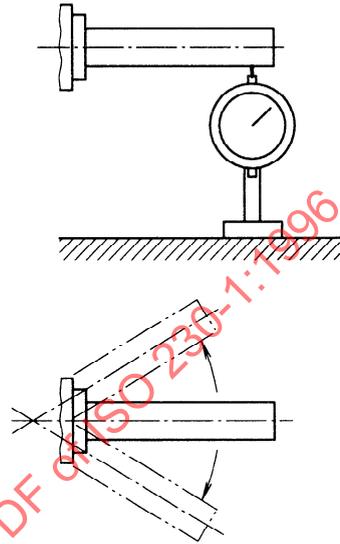


**Figure 60**

### 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 stylus will slide along the cylinder representing the axis (see figure 61). The measurement shall, as far as possible, be made in two perpendicular planes chosen as being of greatest importance in the operation of the machine tool.

NOTE 21 For the deviation of parallelism of the representative cylinder from the axis, see 5.412.1.
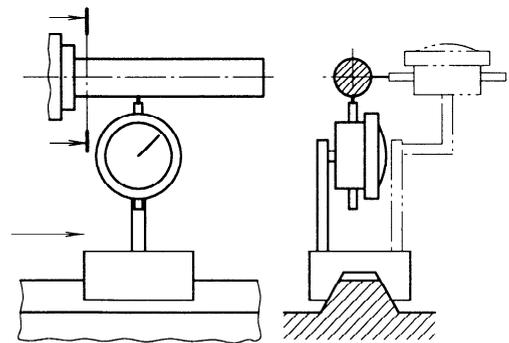


**Figure 61**

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

Where the intersection and the third plane are conveniently situated to one another, a mounting block and precision level are used (see figure 62). The

assembly is moved along the intersection, and changes in the angular readings multiplied by $l$ represent deviations of parallelism (see 5.412.32).
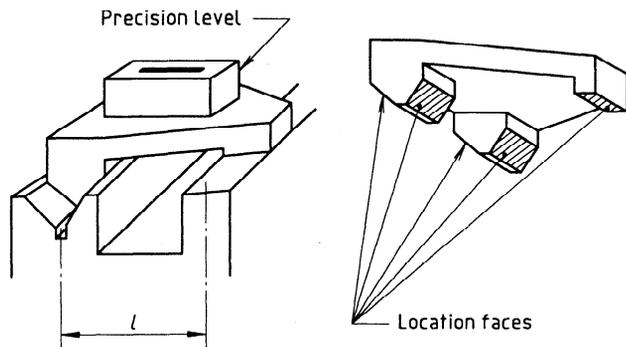


**Figure 62**

If the third plane is not conveniently situated, a mounting block and dial gauge are used (see figure 63). The stylus is positioned at right angles to the third plane and a succession of readings is taken along the line of the intersection.

For other measurement procedures, see 5.412.2.

The included angle between the location faces of the mounting block shall be accurately matched to the intersection angle of the two planes. This can be verified with a marking agent such as jeweller's rouge.
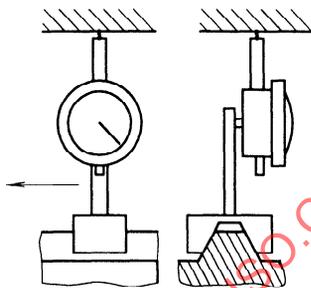


**Figure 63**

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

This measurement may be carried out as in 5.412.5. The stylus of the measuring instrument bears on a vee-block which will slide along the planes forming the second intersection. The measurement shall be made in two planes perpendicular to one another (see figure 64).
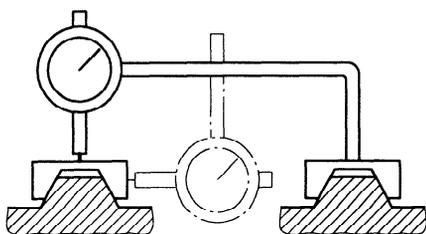


**Figure 64**

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 measurement of parallelism in a vertical plane (see figure 65).

NOTE 22   If a direct measurement of the planes or straight lines concerned is difficult because of interference by components of the machine tool within the field of measurement, the measurement may be related to a reference plane constituted by, for example, a horizontal plane determined by a precision level.
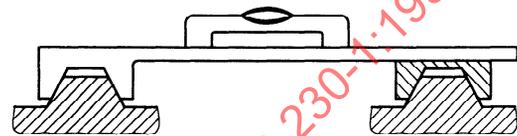


**Figure 65**

### 5.413   Tolerances

Tolerance of parallelism of straight lines or plane surfaces is given as follows:

tolerance of parallelism: . . . mm.

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

0,02 mm for any measuring length of 300 mm.

As a rule, the direction of the deviation is not important; however, if the deviation 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 the results of a measurement depend on the stylus 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 the functional point (see 5.231.2) of a moving part of the machine in relation to:

— a plane (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 usually identical with those used for the measurements of parallelism of lines and planes.

The moving component shall, as far as possible, be driven in the usual way, so as to allow for the effect of clearance and defects 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 stylus bears at right angles to the surface to be measured. The moving component should be moved by the amount stated (see figure 66).

This type of measurement is typically applied on milling and grinding machines where the workpiece is mounted on a worktable.

The dial gauge is mounted in the spindle nose, as shown in figure 66, and the table traversed. The resulting readings will reflect the accuracy (with respect to parallelism) to be expected in the finished workpiece.
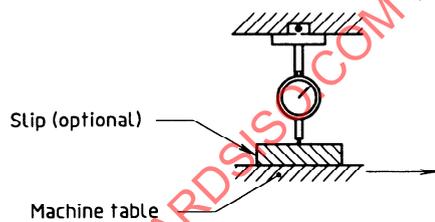


**Figure 66**

##### 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 stylus is at right angles to the surface and slides along it (see figure 67).

If the stylus cannot bear directly on the surface (e.g. the edge of a narrow groove), two alternative methods may be used:

— use of angle lever attachments (see figure 68);

— use of a piece of suitable shape (see figure 69).
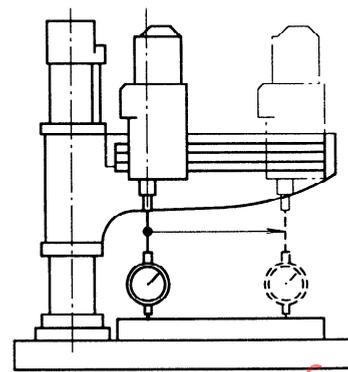


**Figure 67**
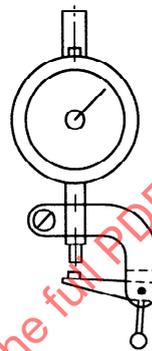


**Figure 68**
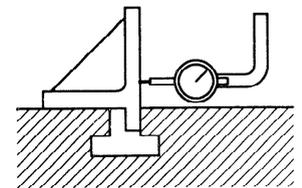


**Figure 69**

#### 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 stylus slides over the cylinder or mandrel representing the axis (see figure 70).

Where there is a rotating axis, the mean position should be used (see 5.412.1).

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



**Figure 70**

26
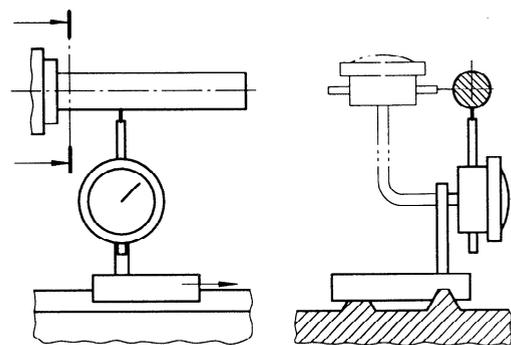
### 5.422.4 Parallelism of a trajectory to the intersection of two planes

Parallelism between each of the two planes and the trajectory shall be measured 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 stylus rests on a given point on the other moving part. The two parts are moved together in the same direction by the same amount as stated, and change in the readings of the measuring instrument is noted (see figure 71).

Unless all planes are of equal importance, this measurement shall be made in two perpendicular planes selected as being those of most importance in the practical use of the machine.
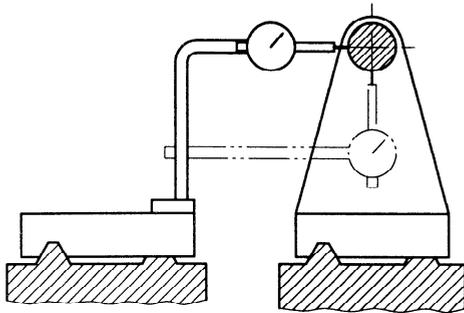
**Figure 71**

### 5.423 Tolerance

Tolerance of parallelism of movement is the permissible change in the shortest distance between the trajectory of a given point on the moving part and a plane, a straight line or other 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, measurements of parallelism (see 5.412.4). A test should first be made to check that the two axes are parallel to the plane, and 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 72).

If these cylinders are not identical, the difference of radius of the tested sections should be taken into account.
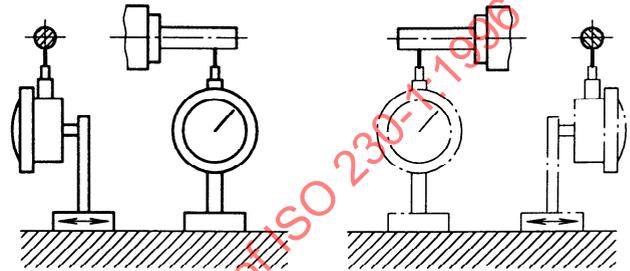
**Figure 72**

### 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 73).

Auxiliary plane
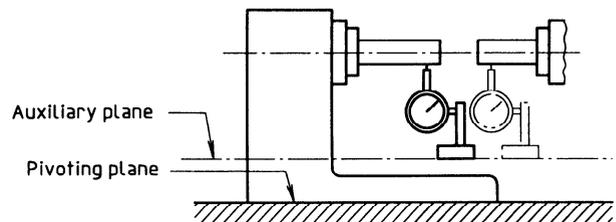
Pivoting plane

**Figure 73**

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 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 23 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

### 5.44 Coaxiality, coincidence or alignment[3]

### 5.441 Definition

Two lines or two axes are said to be coaxial, coincident or in alignment when their relative distance over a given length 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° about an axis. The stylus of the measuring instrument passes in a given section A over the cylinder representing the second axis (see figure 74). Any variation in the readings represents twice the deviation of coaxiality. As the section

chosen for measuring may intersect both axes, the check shall be made in a second section B.

If the deviation is to be determined in two specified planes (e.g. planes H and V in figure 74), 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 high 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 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 measuring instruments 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 mandrel, 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 the clearance in the ring (see figure 75).

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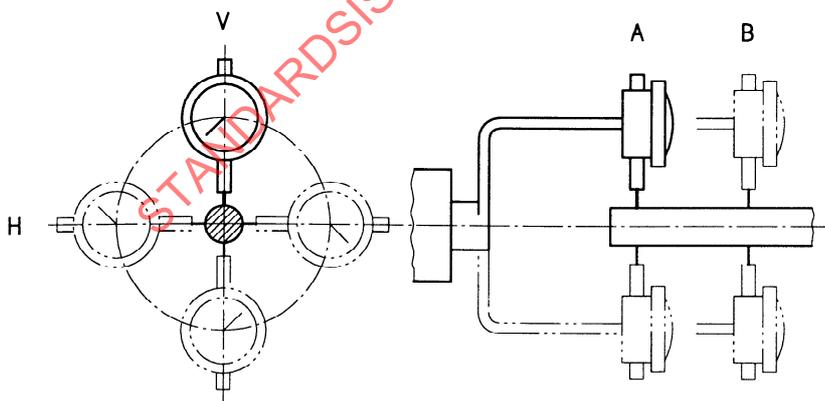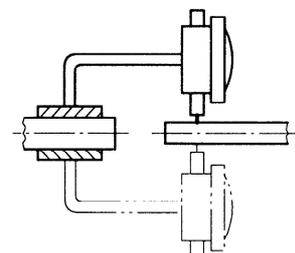


**Figure 74**



**Figure 75**

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3) The word alignment is sometimes used in practice 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.

### 5.443 Tolerance

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

tolerance of coaxiality of axis 1 to axis 2 is: ... mm over the given length.

In special cases, an additional indication may be given depending on operating conditions, 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 coaxiality, a further tolerance on parallelism between the two axes (see figure 76).

a) Tolerance of coaxiality of axis 1 to axis 2 is: $T$ mm over the given length.

b) Tolerance of parallelism between axis 1 and axis 2 is: $T'$ mm over the given length ($T' < T$).
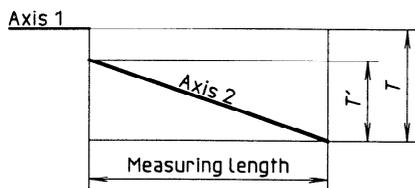


**Figure 76**

## 5.5 Squareness or perpendicularity

Squareness and perpendicularity are generally used with the same meaning.

Squareness and perpendicularity measurements address 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 deviation 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 measurement of squareness is, in practice, the measurement of parallelism. The following general statements 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 stylus 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. The deviation of parallelism between the plane of the circumference and the plane may be measured by sweeping the plane to be checked by means of the stylus of the dial gauge.

This deviation is expressed in relation to the diameter of the circle of rotation of the instrument (see figure 77).

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

b) 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.



**Figure 77**

In order to eliminate the effect of periodic axial slip (see 5.621.2) of the spindle, which may make the measurement 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, provided the dial gauges are zeroed in the same contact point.

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.

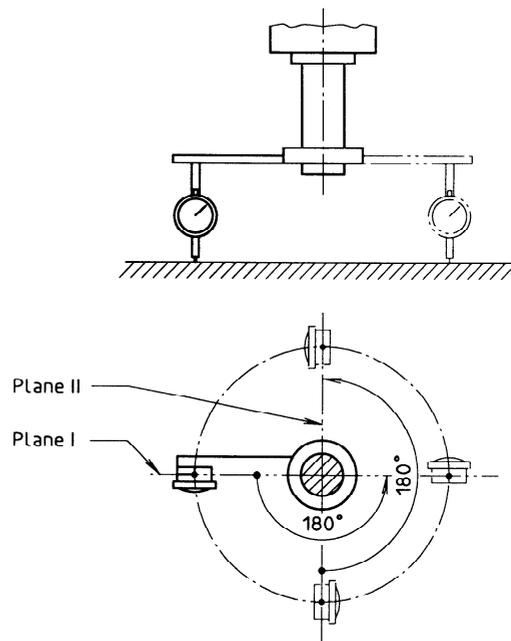Finally, the minimum axial play shall, if necessary, be eliminated by means of a suitable axial pressure (see 5.621.1).

### 5.512.2 Two planes at 90° to each other

A cylindrical square is set on one of the planes (see figure 78). The dial gauge is moved along the other plane and readings taken at regular intervals. The cylindrical square is then rotated through 180° and a second set of readings is taken. An average value is then obtained from the two sets of readings.
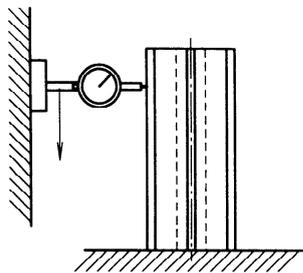


**Figure 78**

### 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 79). Parallelism between the free arm and the second axis is measured by the method described in connection with the measurement of parallelism (see 5.412.4).



**Figure 79**

### 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 80). Change 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 measurement of parallelism (see 5.412.1).
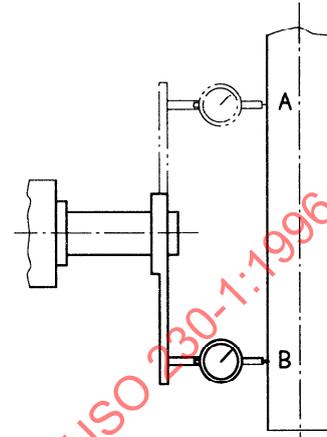


**Figure 80**

### 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 81).

Parallelism of the free arm to the plane is measured in two perpendicular directions by the method given in connection with the measurement 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 Fixed axis

A square with a suitable base is brought into contact with the cylinder representing the axis (see figure 82). Parallelism between its free arm and the intersection is measured by the method proposed in connection with the measurement of parallelism (see 5.412).



**Figure 81**        **Figure 82**

### 5.512.52 Axis of rotation

A dial gauge is attached to an arm held on the spindle, the stylus being against a block which rests on the two intersecting planes' surfaces. The spindle is given half a turn and the vee-block moved to bring the stylus into contact with the same point on the block (see figure 83).



**Figure 83**

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

A square (see figure 84) or a dial gauge (see figures 85 and 86), as appropriate, is fitted with a suitable base, allowing it to rest on the intersecting planes.
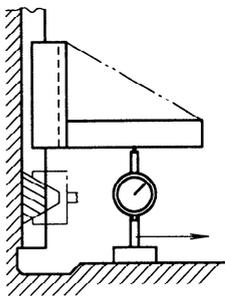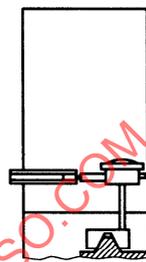


**Figure 84**          **Figure 85**

Parallelism between its free arm and the third plane or the intersection may be measured by the method described in connection with the measurement of parallelism (see 5.412.2 or 5.412.6). The measurement shall be made as far as possible in two perpendicular planes (see figures 85 and 86).
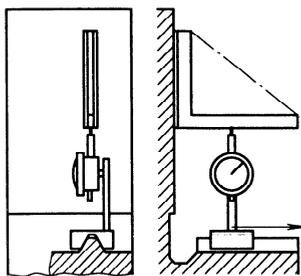


**Figure 86**

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

A square with a suitable base is placed on one of the intersections. The parallelism of the free arm to the second straight line of intersection is checked by the method described in connection with the measurement of parallelism (see 5.412.6).

NOTE 24   If direct measurement of the planes and straight lines concerned is difficult due to the distance between them, or due to interference by machine components, the measurement may be made in relation to a reference plane, e.g. by the use of a level.

### 5.513 Tolerance

The tolerance of squareness may be given in two ways.

1) When squareness is measured using a reference square, the tolerance of squareness is given similar to the tolerance of parallelism.

   i.e. Tolerance of squareness: . . . mm for any measuring length of . . . mm

2) When squareness referred to an axis is measured as the difference of readings on a measured diameter.

   i.e. Tolerance of squareness: . . . mm/ . . . mm

When the deviation of squareness is allowed in only one direction, the direction shall be indicated, e.g. free end of spindle on the column side only (referred to the table surface in the case of a vertical spindle).

## 5.52 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.

### 5.522 Methods of measurement

### 5.522.1 General

The measurement of perpendicular motion becomes a measurement of parallelism by the use of a square suitable for the given conditions (see 5.42).

The moving part should be driven in the usual way to display the effects of play and defects in the slideways.

### 5.522.2 Perpendicularity between the trajectory of a point and a plane

A square is placed on the plane (see figure 87). Parallelism between the motion and the free arm shall be measured in two perpendicular directions, in accordance with 5.422.22.
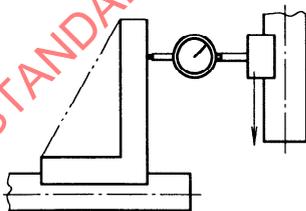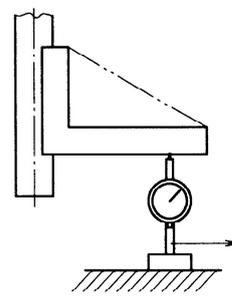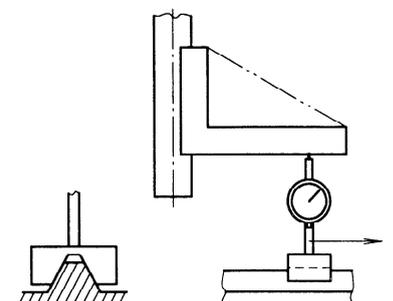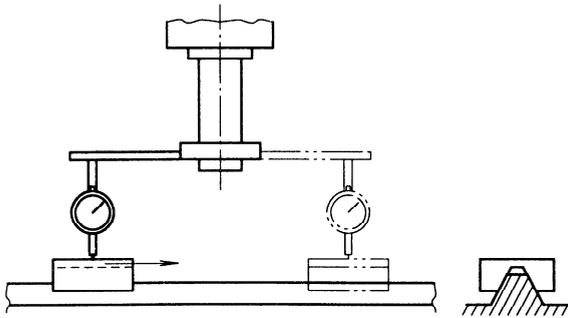


**Figure 87**

### 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 88). The measurement of parallelism between the motion and the free arm of the square shall be made in accordance with 5.422.22.
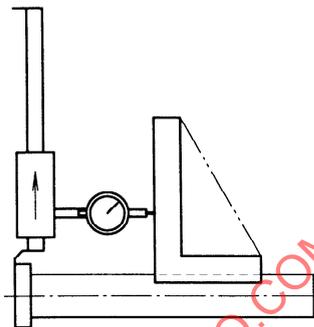


**Figure 88**

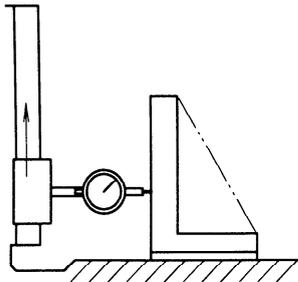If the axis is one of rotation, the mandrel representing the axis shall be placed in the mean position of its run-out in the measuring plane. In the particular case of a lathe headstock spindle capable of taking a face plate, a face plate shall be mounted. First, read the dial gauge at a point of the face plate which is on the diameter parallel to the movement. A second reading shall be made at the same point after rotating the spindle 180°. The algebraic mean of the two readings gives the deviation of squareness 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 measuring instrumentation assembly is shown in figure 89.

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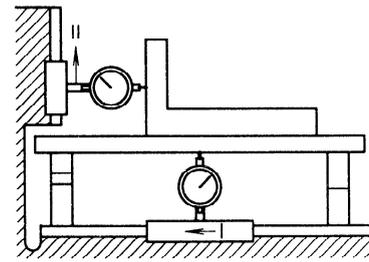


**Figure 89**

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 deviation of perpendicularity shall be equal to the difference in the range of 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 measurement may also be carried out by means of optical methods (see figure 90).
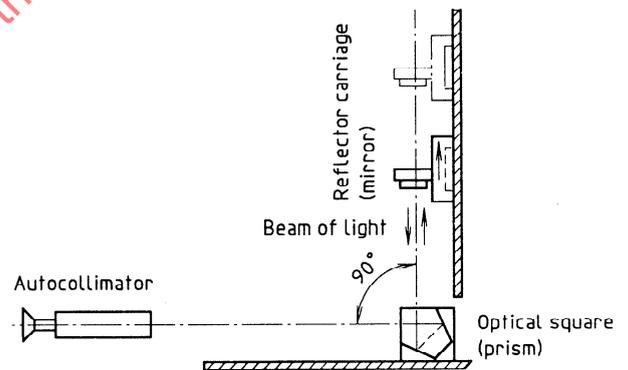


**Figure 90**

### 5.523 Tolerance

Tolerance of 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.

For the method of determining the tolerance, see 5.513.

## 5.6 Rotation

Rotation-related measurements address 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

Out-of-round is the error of the circular form of a component in a plane perpendicular to its 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 circumscribed 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 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 in as close accordance as possible with the definition.

#### 5.611.2 Eccentricity (see figure 91)

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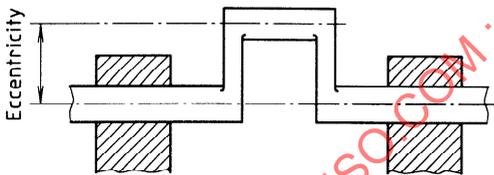


**Figure 91**

#### 5.611.3 Radial throw of an axis at a given point

When the geometric axis of a part does not coincide with the rotating axis, the distance between these two axes is called radial throw (see figure 92).
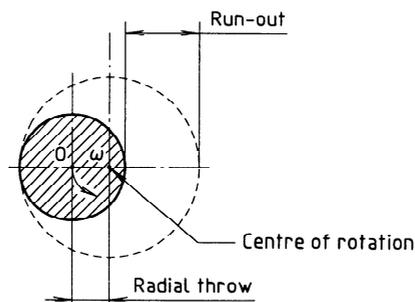
#### 5.611.4 Run-out of a component at a given section

If no account is taken of the out-of-round, the run-out is twice the radial throw of the axis in a given section (see figure 92).

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

— the radial throw of the axis,

— the out-of-round of the component, and

— radial error motion of the axis of rotation (the errors of bearings).

It is important to note that in geometric 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 term run-out is 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 to be divided by two. The proposed measuring methods take this note into consideration.

NOTE 25   With rolling bearings, the rollers and cage rotate once for more than two rotations of the shaft and it is common for the run-out of a shaft to repeat cyclically every several rotations. Run-out should therefore be measured over several rotations, but at least two rotations.

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 run-out at each measuring point does not exceed the allowed value.

### 5.612 Methods of measurement

#### 5.612.1 Precautions before testing (see 3.22)

Before the test 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.

Axis of rotation = ω
Geometrical axis = 0



**Figure 92**

### 5.612.2 External surface

The stylus of a dial gauge is brought into contact with the revolving surface to be measured and the readings of the instrument observed while the spindle is slowly rotated (see figure 93).



**Figure 93**

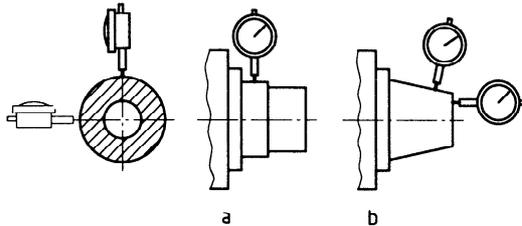On a conical surface, the stylus is set at right angles to the generating line, and the influence of the taper on the results shall be calculated. Furthermore, the diameter of the circle being checked will vary if there is any axial movement in the spindle during its rotation. This causes the run-out to appear greater than it actually is. Therefore a conical surface shall only be used for measuring the 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 measurement is computed according to the angle of taper.

The measured results can be affected by the lateral thrust on the stylus of the dial gauge. To avoid errors, the stylus shall be strictly aligned with the axis of the revolving surface.

### 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 would be determined. As the axis of the mandrel may cross the axis of rotation in the measurement plane, measurement should be done at two sections A and B which are a specified distance apart (see figure 94).

For instance, one measurement should be made close against the housing of the mandrel and another at a specified distance from it. Due to potential nesting problems when 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.

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 94).
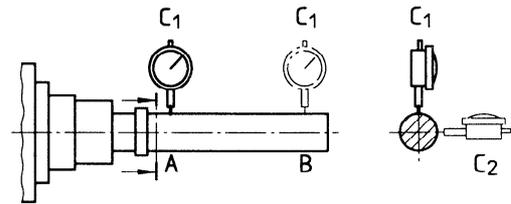


**Figure 94**

The above methods require the following comments:

Steps should be taken to minimize the effect of the tangential drag upon the stylus of the measuring instrument.

When using a test mandrel, the exact shape of the bore is not revealed.

A check of the run-out of the spindle by machining and testing a cylindrical workpiece will take into account only defects in the bearings of the spindle. This practical turning test 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 with ball and roller bearings. Spindles which are automatically centred during rotation (e.g. by hydraulic pressure) can be tested only when running at normal speed. In such a case, instruments involving no contact shall be used, e.g. a capacitative pickup, an electromagnetic pickup or any other suitable instrument.

### 5.613 Tolerance

The tolerance on the run-out is the deviation permissible in the trajectories of points at a section of the revolving 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 (defects in 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 measurement plane, but for longer surfaces the measurement planes shall be specified.

When it is desired to specify the measurement 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

Minimum axial play is 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 95).

#### 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 force $P$ in a given direction (see figure 95).

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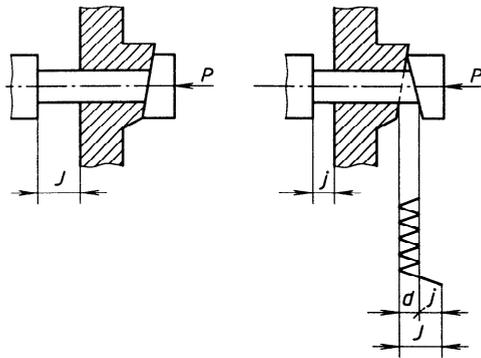


$J$ = Maximum axial play
$j$ = Minimum axial play
$d$ = Periodic axial slip

**Figure 95**

### 5.622 Methods of measurement

#### 5.622.1 General

In order to eliminate the effect of play in thrust bearings, a slight force shall be applied to the spindle in the direction of measurement. The stylus of the dial gauge should be applied to the centre of rotation of the front face. Readings are taken while the spindle is rotated continuously at slow speed, force being maintained meanwhile in the stated direction.

If the spindle is hollow, a short mandrel should be fitted with a plane face perpendicular to the axis against which a stylus with a rounded contact point may bear (see figure 96). Alternatively, a mandrel with a rounded face may be used with a stylus having a flat contact point (see figure 97). If the spindle has a centre, a steel ball should be inserted for a flat contact point to bear against (see figure 98).
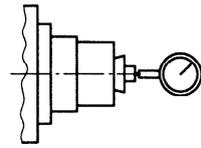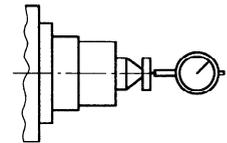


**Figure 96**              **Figure 97**
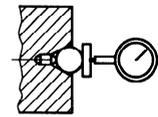


**Figure 98**

#### 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.

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. However, when using a preloaded thrust bearing, no force need be applied to the spindle.

If it is impossible to place a dial gauge on the axis, the value of the axial slip may be obtained by using two dial gauges (see figure 99). Readings are taken at various angular positions. The axial slip is equal to the difference between the largest and smallest mean values.

NOTE 26   If the thrust bearing is of the ball- or roller-type, the measurement should be made through at least two revolutions.

Steps should be taken to minimize the effect of the tangential drag upon the stylus of the measuring instrument.



**Figure 99**

### 5.623 Tolerance

The tolerance on axial slip defines the limit of the axial slip of the spindle during slow rotation with a slight axial force. The direction of this force should be indicated (e.g. 'applying a slight force towards the housing'). It may be necessary to make two measure-

ments, by applying the force first in one direction and then in the opposite direction; in this case, different tolerances for the two directions may be stated.

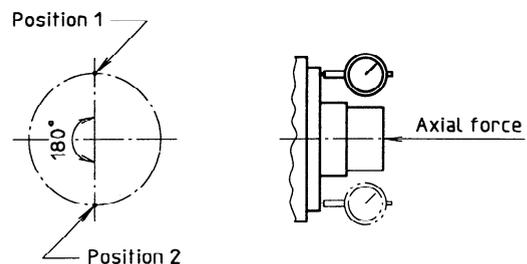### 5.63 Camming

#### 5.631 Definitions

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 figures 100, 101 and 102):

a) surface not flat;

b) surface and axis of rotation not perpendicular;

c) periodic axial displacement of the axis.

NOTE 27 When the plane concerned has a geometric axis (part A, figure 103) 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.
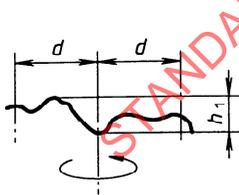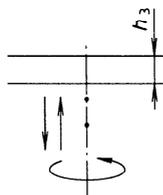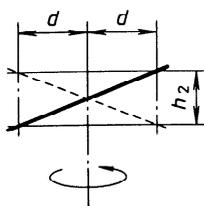


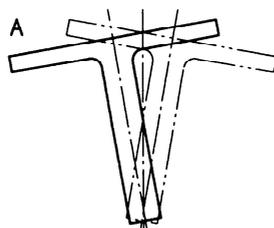**Figure 100**  **Figure 101**

**Figure 102**  **Figure 103**

#### 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 from the axis of rotation, measurement 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 perpendicular to the face (see figure 104), and placed successively at a series of points spaced around the periphery. The difference between the maximum and minimum readings will be noted at each of these points; the greatest difference will be the camming. The spindle should make continuous revolutions at slow speed, and should receive a slight end-force 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 a slight force is applied to the spindle during the test should be specified (e.g. applying slight force towards the housing).
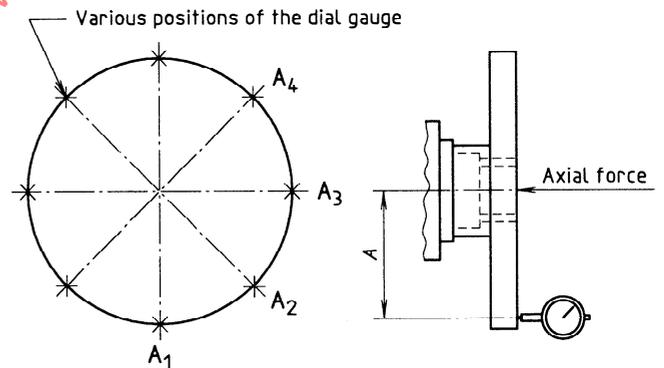


**Figure 104**

NOTE 28 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 stylus 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 circumfer-

ence of the surface to be measured. 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 95 and 100 to 102).

# 6 Special tests

## 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 recognized:

a)  individual error of division;

b)  successive error of division;

c)  local error of division;

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

e)  total error of division.

#### 6.111 Individual error of division

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

EXAMPLE

(ab − a'b') for the second division of figure 105 (a division is considered here 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 is equal to the algebraic difference of the individual errors of two divisions.

EXAMPLE

(ab − a'b') − (bc − b'c') = ab − bc  in  figure 105  for the second division, relative to the third division.

#### 6.113 Local error of division

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 106.

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 $k$ 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 105).

### 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 108.

### 6.116  Graphic representation of these errors

Take a graduated scale, giving, with the theoretical scale, the steps indicated in figure 105:

1)  If a diagram is drawn (see figure 106), 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 107), 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 position of every division in relation to its theoretical position (see figure 108), the maximum amplitude RS, shown by the diagram, represents the total error of division.

It should be noted that figure 106 can be deduced from figure 108 as follows: the ordinate of step $k$ of figure 106 is equal to the difference between the ordinates of the steps $k$ and $k − 1$ of figure 108[4].

---

4)  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 105).

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**Figure 105**

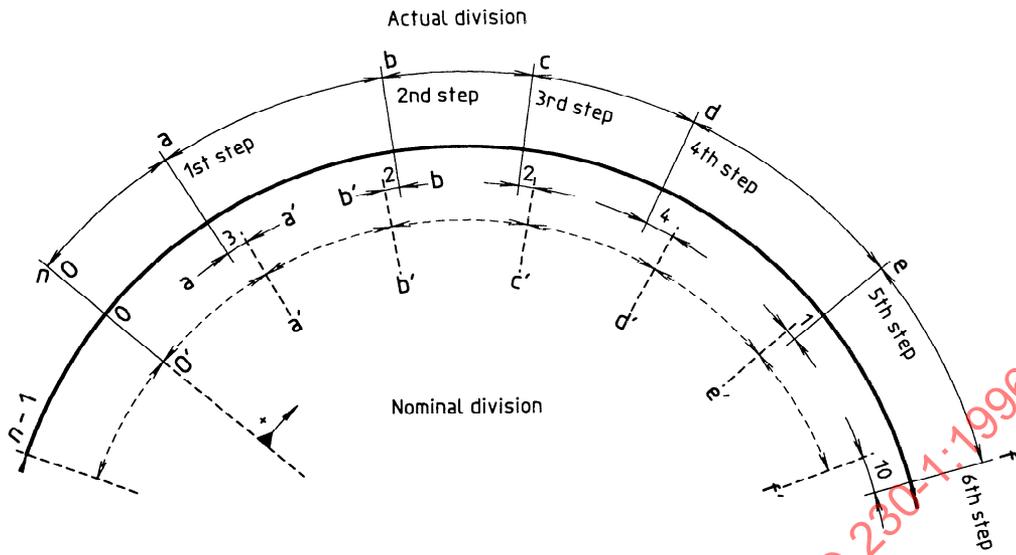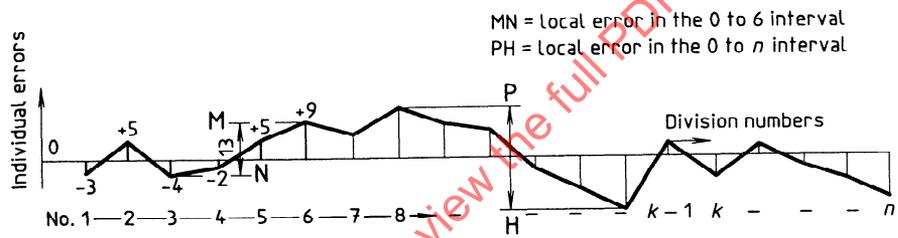Determination of local error of division

MN = local error in the 0 to 6 interval
PH = local error in the 0 to n interval



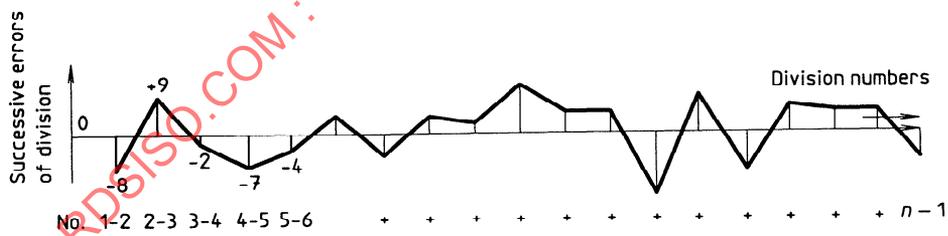**Figure 106**

Successive errors of division



**Figure 107**
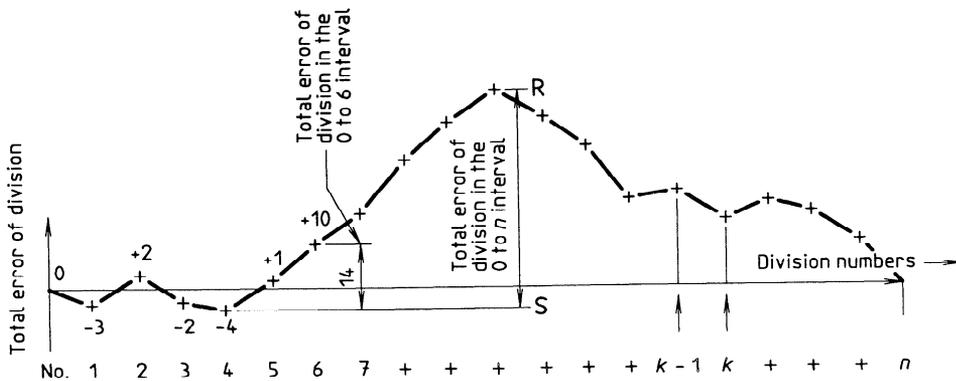
Determination of the total error of division



**Figure 108**

## 6.12 Methods of measurement

As the measurement of errors of division usually requires special instruments, reference should be made to technical notes dealing with this subject.

## 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; for circular division, the individual and total errors are usually given.

NOTES

29   When testing machine tools, errors of division normally include errors caused by the control devices used in the division. Individual values of partial errors (i.e. errors of division, 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.

30   Attention is 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 deviation of concentricity of its mounting on the axis of the machine spindle.

## 6.2   Determination of the linear positioning deviations of screw-driven components

In order to determine these deviations, it may be necessary to examine the geometric aspect of all the elements which might play a part in the deviations, and in particular the lead screw.

Typically, any set of errors observed is made up of two components, cyclic error and progressive error, ignoring the effect of errors due to repeatability and time. Cyclic error can be considered as any error component which repeats itself at least once along an axis of the machine tool, and progressive error as a non-cyclic error. Especially with machines that position directly off the lead screw, cyclic error can contribute a large proportion of the total error.

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 components and deflections may be important. It may be possible to attach to each of the factors concerned individual tolerances in such a way that the overall tolerance corresponds to the expected accuracy of the machine.

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

For a geometric test, there are a number of methods that can be used. These include using a master screw and dial gauge, gauge blocks and dial gauge, or laser interferometry.

For a machining test, a workpiece is machined and given lengths on it are measured; e.g. in the particular case of a lathe lead screw, a machining 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 which may exist in its locking system when the component has been locked.

### 6.32   Method of measurement (testing of the indexing device/component)

This test may be made by fixing a bar of sufficient length perpendicular to the rotational axis to effect the measurement over a known distance on an indexing device/component. At this distance, a dial gauge is mounted so that its stylus bears against the bar. A torque is exerted on the indexing device in one direction, then in the opposite direction, and differences are read off the dial gauge. The value of the torque should be so selected as not to add any significant errors due to deflection of the indexing device/component.

### 6.33   Tolerance

The tolerance of angular play is the maximum allowed angular play, expressed as an angle or as tangent of that angle.

## 6.4   Repeatability of devices with angular indexing

### 6.41   Definition

Repeatability of angular indexing is defined as the maximum difference (range) of angular displacement resulting from a series of trials when approaching any angular target position under the same conditions of direction and speed of approach (where applicable, clamping will take place at the end of each approach and angular play will be included).

For the repeatability of continuous numerically controlled angular positioning, see ISO 230-2.

## 6.42 Method 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 maximum difference between the readings made between successive locking represents the repeatability corresponding to this position. Measurements shall be repeated at each indexing position.

## 6.43 Tolerance

The tolerance of repeatability is the allowed range of the measured angular deviations, expressed as an angle or as a tangent of that angle. It includes the tolerance of the angular play (in fact, the tolerance of repeatability cannot be fixed independently of tolerances of angular play).

## 6.5 Intersection of axes

### 6.51 Definition

Two non-parallel axes are said to intersect when the shortest distance between them lies within the specified tolerance.

### 6.52 Methods of measurement

#### 6.521 Direct 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 axes. Measurements are taken between the two flat faces to determine the deviation of intersection (see figure 109).
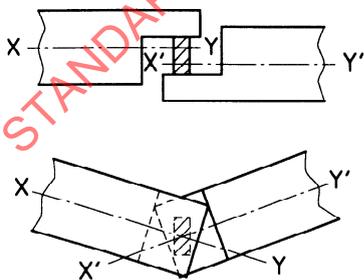


**Figure 109**

#### 6.522 Indirect measurement

Indirect measurement can be made by using a separate reference plane, for example a surface plate which is set up parallel to the two axes. Independent measurements are taken from the reference plane to each axis and compared.

## 6.53 Tolerance

The distance between two intersecting axes, when it is not important that axis 1 pass before or behind axis 2, is given as follows:

distance of axis 1 to axis 2: ± . . . mm

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

. . . mm when axis 1 is to be higher than axis 2

## 6.6 Circularity

### 6.61 Definition

A line situated in a plane is said to be circular when all its points are contained between two concentric circles whose radial separation does not exceed a given value (see figure 110).
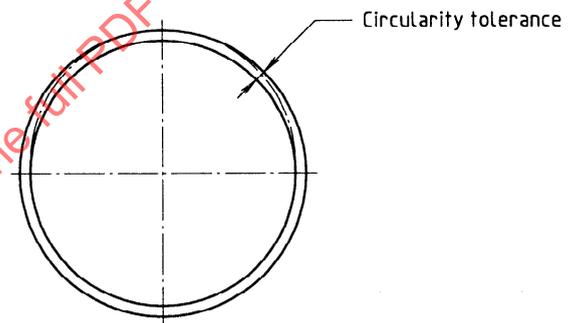


**Figure 110**

Circularity may refer either to the shape of a test piece or to the shape of the path described by a moving component(s).

### 6.62 Methods of measurement on test pieces

#### 6.621 Circularity measuring machine with rotating pickup or rotating table

In both cases the test piece is centred on the table (small eccentricities may be compensated for). In the first case the instrument is rotated around the test piece (see figure 111), while in the second the table rotates (see figure 112). A polar diagram is plotted from which the circularity is evaluated.
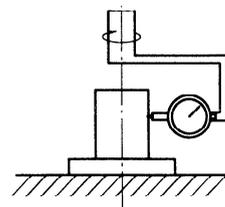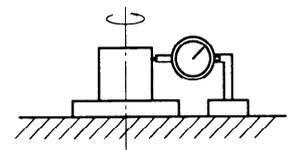


**Figure 111**          **Figure 112**

## 6.622 Coordinate measuring machine

An instrument moving along the circumference establishes the position of each point in the form of $X$ and $Y$ coordinates (see figure 113). From this data, the circular profile and circular deviations are determined.
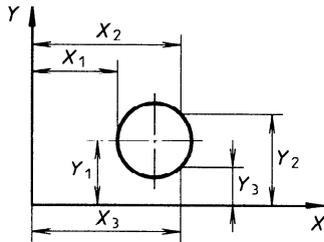


**Figure 113**

## 6.623 Projection of the profile

The profile to be checked is projected onto a screen to produce an image of the circumference (see figure 114). The two concentric circles represent the tolerance zone and the circularity deviation.

NOTE 31   This method is limited to smaller test pieces by the size of the projector.
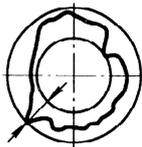


**Figure 114**

## 6.624 Vee-block method

The test piece is supported on two vee-blocks (preferably with an included angle of 108°). The test piece is rotated and the deviation of circularity is measured by a dial indicator (see figure 115).
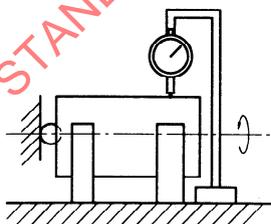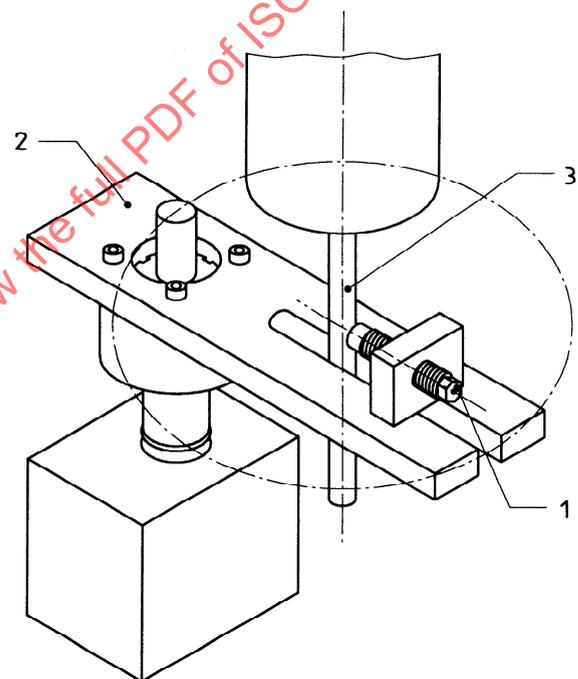


**Figure 115**

## 6.63 Measurement of numerically controlled (NC) circular movements

Circular movements may be affected by the applied feed rate. The results are comparable to the results obtained on machined parts, if diameter and feed rate are the same for machining and for direct measurement of the circular movement.

## 6.631 Rotating one-dimensional probe

A one-dimensional probe, e.g. an electronic probe, is moved by the NC machine on a circular path. The probe is rotated by a special rotary fixture and measures displacement relative to a test mandrel (figure 116) or a circular master (see figure 118) or a target fixed on a special rotary fixture 2 and rotated in conjunction with the probe (see figure 117). The signal of the probe is plotted on a circular diagram (a circular diagram is shown in figure 110). The circular diagram can be produced, e.g. by a synchronized polar plotter, by computer evaluation or by use of an additional rotary resolver in the rotary fixture and a polar plotter.
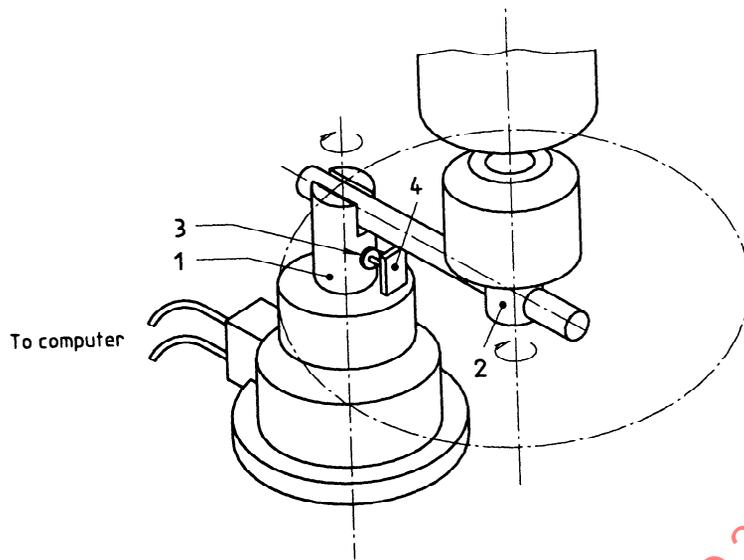


1   One-dimensional probe
2   Special rotary fixture
3   Test mandrel

**Figure 116**

## 6.632 Circular master and two-dimensional probe

A two-dimensional probe is moved by the NC machine on a circular path relative to a circular master without rotating the probe (see figure 118). The programmed diameter of the circular path is chosen so that the two-dimensional probe keeps in contact with the circular master. The two signals of the probe are plotted directly on an $XY$-plotter that produces the circular diagram (a circular diagram is shown in figure 110).

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To computer

1 Special rotary fixture 1
2 Special rotary fixture 2
3 One-dimensional probe
4 Target

**Figure 117**
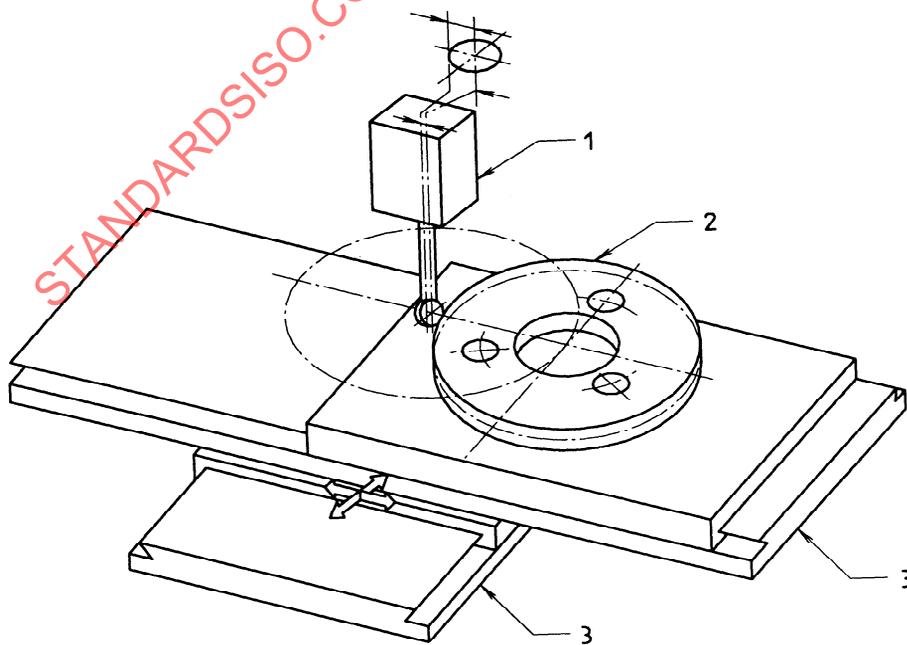


1 Two-dimensional probe
2 Circular master
3 Slide of the machine

**Figure 118**

**Figure 119**

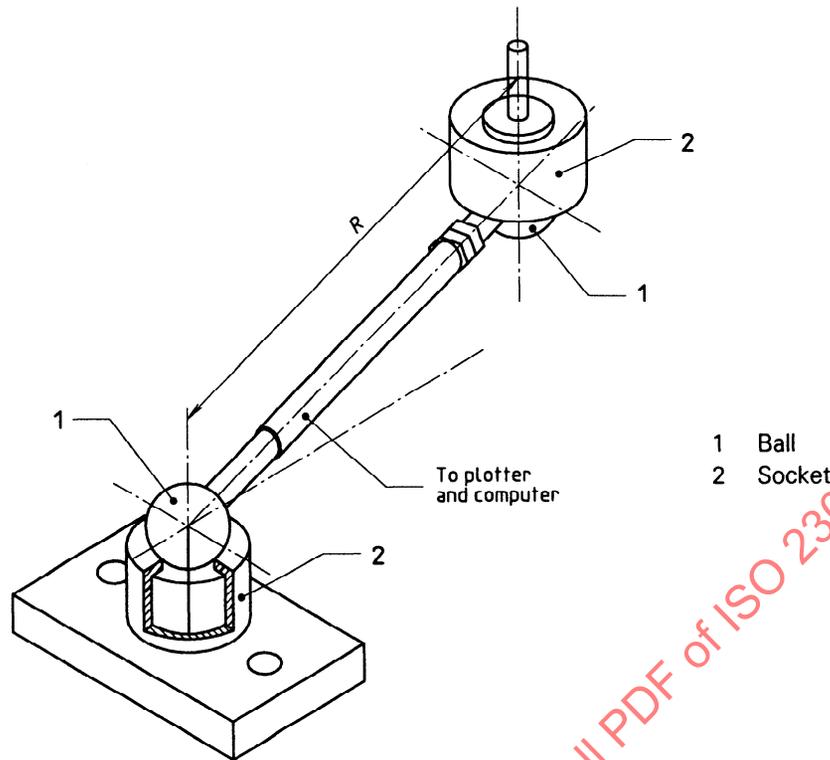### 6.633 Telescopic ball bar

A telescopic ball bar (see figure 119) is attached by suitable sockets on the NC machine, one socket on the table of the machine and one socket on the spindle head which is moved on a circular path relative to the table. A change in the distance $R$ between the two balls is measured. The measurement signal is plotted on a circular diagram (a circular diagram is shown in figure 110). The circular diagram can be produced e.g. by a synchronized polar plotter or by computer evaluation.
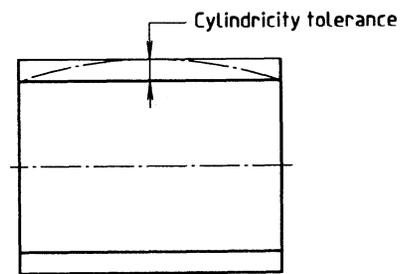
## 6.7 Cylindricity

NOTE 32 Although the control of circularity, straightness and parallelism by means of a cylindricity tolerance may appear to be a convenient technique, the measurement of cylindricity in accordance with its definition may present considerable difficulties. It is recommended that individual characteristics comprising cylindricity be toleranced separately, as appropriate to the part concerned.

### 6.71 Definition

A surface is said to be cylindrical when all its points are contained between two coaxial cylinders of revolution whose radial separation does not exceed a given value (see figure 120).

### 6.72 Methods of measurement

All the procedures involve a measurement of dimensional deviation with respect to a reference of cylindricity.

1  Ball
2  Socket



**Figure 120**

### 6.721 Coordinate measuring machine

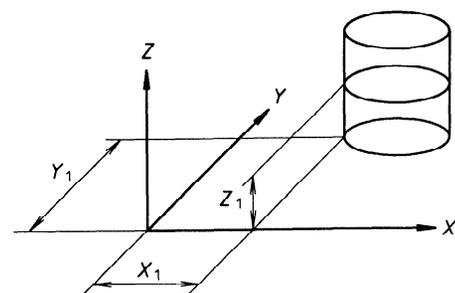The circular profile of each section is determined by scanning the circumference with a probe (see figure 121).



**Figure 121**

### 6.722 Circularity measuring machine with rotating probe or rotating table

In both cases the test piece is centred on the table and the probe can be moved parallel to the axis of the rotating table. In the first case the probe is rotated around the test piece (see figure 111), while in the second the table rotates (see figure 112). The cylindricity is determined by superimposing the polar diagrams taken at various sections.

NOTE 33 This method gives high accuracy with easy alignment, but requires expensive equipment.

### 6.723 Vee-block method

The test piece is supported on two vee-blocks (preferably with an included angle of 108°). The test piece is rotated and the deviation of circularity is measured by a dial indicator (see figure 115). The procedure is repeated at a number of sections to provide an indication of cylindricity.

## 6.8 Consistency of machined diameters

### 6.81 Definition

Diameters are said to be consistent when the variation between machined diameters at intervals along the test piece, measured in a single axial plane, fall within given maximum and minimum diameters (see figure 122).

## 6.82 Methods of measurement

### 6.821 Micrometer or similar two-point measuring instrument

Readings are taken at each band in one plane only. Measurements can be taken while the test piece is still on the machine tool (see figure 123).
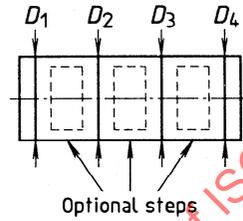


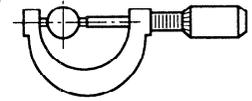$D_1$  $D_2$  $D_3$  $D_4$

Optional steps

**Figure 122**  **Figure 123**

### 6.822 Height gauge

The test piece is fixed horizontally between centres or supported by vee-blocks. The highest and lowest points of the machined diameters are measured using a height gauge (see figure 124).
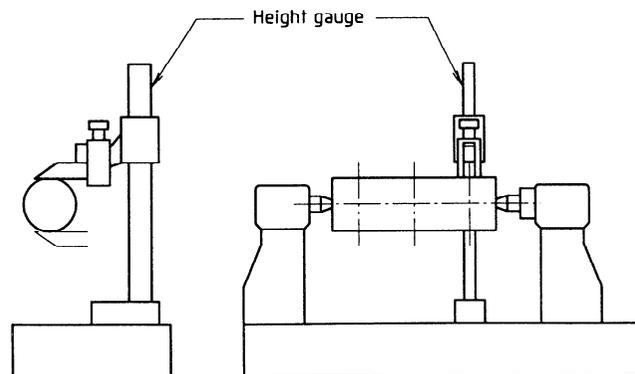


Height gauge

**Figure 124**

# Annex A
(informative)

# Instruments and equipment for testing machine tools

## A.1 General

The measuring equipment described in this annex is used for the geometric testing of machine tools. Where necessary, reference is made to the appropriate International Standards.

Clauses A.2 to A.5 describe the precision instruments used for the testing of machine tools. Their accuracy is that of measuring instruments for inspection purposes (not for standard rooms).

Where practicable, measurement errors for these instruments should be equal to or less than 10 % of the tolerance zone for the feature being checked.

The measuring equipment should be calibrated at regular intervals in comparison with known reference standards, with respect to the metrological requirements. If necessary, calibration charts shall be supplied to show the condition of the equipment.

Measuring equipment should not be used until it has been allowed to stabilize at the ambient temperature, and be kept as stable as possible during the test procedure.

Care should be taken to prevent disturbance to the equipment due to vibrations, magnetic fields, electrical interference, etc.

## A.2 Straightedges

### A.2.1 Description

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

There are two principal types of straightedge:

— the bow-shaped straightedge [see figure A.1 a)] with a single edge;

— the straightedge with two parallel faces.

The latter type may be:

— single-section with a solid or lightened web [see figure A.1 b)].

— of plain rectangular section [see figure A.1 c)];

Straightedges should preferably be heat-treated and stabilized.

## A.2.2 Accuracy

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

### A.2.21 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 0,01 mm per 1 000 mm.

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

### A.2.22 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 A.1) shall not exceed the following amounts:

$$\frac{(2 + 0{,}01L)}{1\ 000}$$

where $L$ is the working length, in millimetres.

In addition, the errors over any length of 300 mm should not exceed 0,005 mm.

### A.2.23 Parallelism of working faces

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

$$\frac{1{,}5\ (2 + 0{,}01L)}{1\ 000}$$

### A.2.24 Straightness of side faces, in millimetres

$$\frac{10\ (2 + 0{,}01L)}{1\ 000}$$

### A.2.25 Parallelism of side faces, in millimetres

$$\frac{15\ (2 + 0{,}01L)}{1\ 000}$$

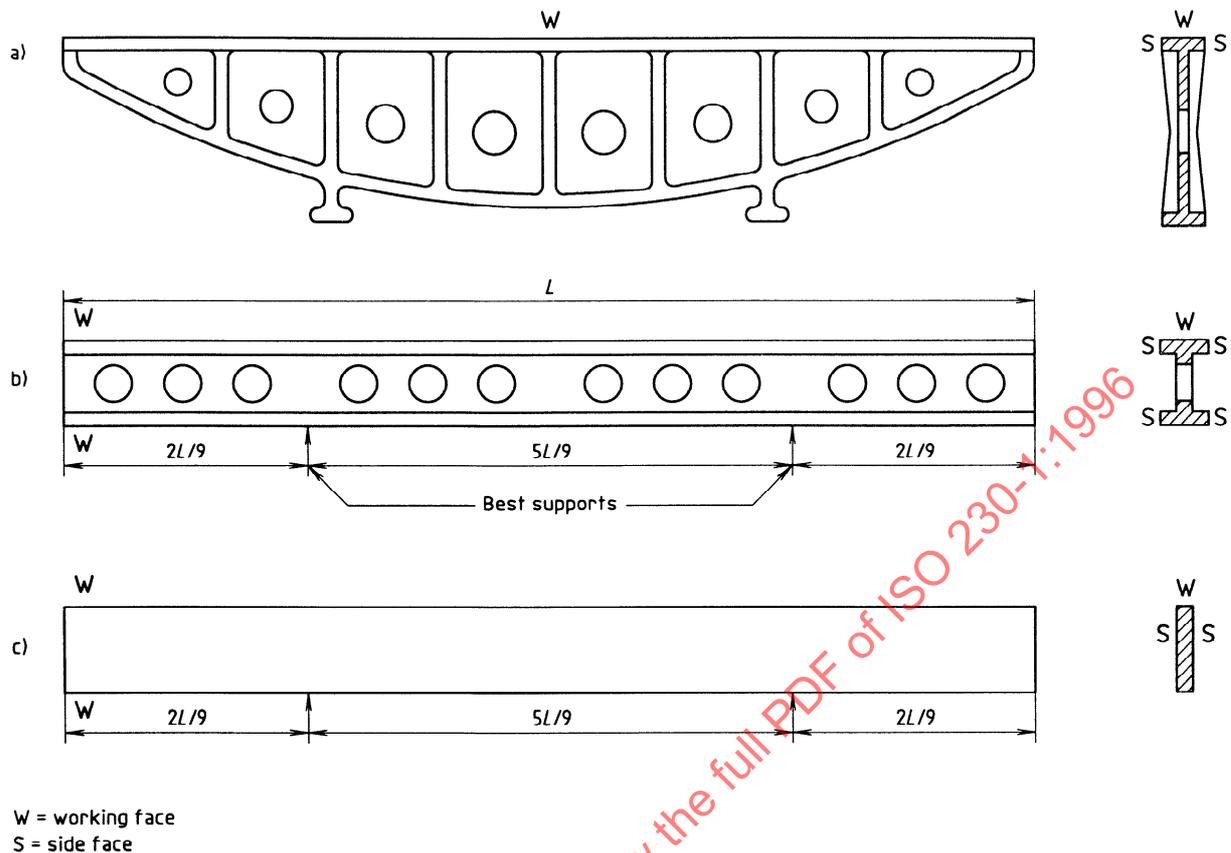W = working face
S = side face

**Figure A.1 — Positions of best supports for straightedges**

### A.2.26 Squareness of side faces to working faces

± 0,002 5 mm for a measuring length of 10 mm

### A.2.27 Surface finish of working faces

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

### A.2.28 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.

## A.2.3 Precautions in use

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

In the latter case, the supporting positions should be chosen preferably so as to minimize the natural deflection. In case of straightedges of a uniform cross-section, their supports should be separated by $5L/9$,

and situated at a distance of $2L/9$ from the ends (see figure A.1). 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 when it is supported at the extreme ends, its natural deflection should be taken into account.
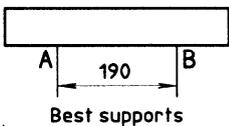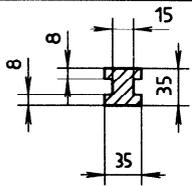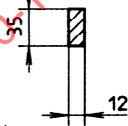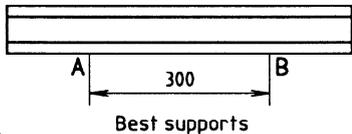
Table A.1 shows, as examples only, five straightedges of various lengths which would conform to these conditions. The natural deflection depends directly upon the modulus of elasticity $E$ of the material used. The values of the deflection given in table A.2 correspond to straightedges made of ordinary cast iron: $E = 98$ kN/mm². In the case of steel, $E = 196$ kN/mm², the deflections would be halved. In the case of high-duty cast iron, where for example $E = 147$ kN/mm², the deflection would be proportional to the modulus of elasticity.

## A.3  Test mandrels with taper shanks

A test mandrel represents, within given limits, the axis which is to be checked, either for run-out or for position in relation to other components of the machine.

## Table A.1 — Straightedges

Dimensions in millimetres

| No. | Length | | Diagram | Broad type | | Normal type | |
|---|---|---|---|---|---|---|---|
| | Working | Total[1] | | Section | Mass[2] kg | Section | Mass[2] kg |
| 1 | 300 | 340 | A ─ 190 ─ B   Best supports | (section drawing, 8, 8, 15, 35, 35) | 2 | (section drawing, 35, 12) | 1 |
| 2 | 500 | 540 | A ─ 300 ─ B   Best supports | (section drawing, 8, 8, 15, 50, 35) | 4 | (section drawing, 50, 15) | 3 |
| 3 | 800 | 840 | 13 holes ⌀ 40   A ─ 465 ─ B   Best supports | | | (section drawing, 8, 8, 80, 35) | 5 |
| 4 | 1 000 | 1 040 | 13 holes ⌀ 50   A ─ 575 ─ B   Best supports | | | (section drawing, 12, 12, 100, 40) | 12 |
| 5 | 1 600 | 1 640 | 4 holes ⌀ 100   6 holes ⌀ 80   A ─ 910 ─ B   Best supports | | | (section drawing, 12, 180, 12, 50) | 33 |
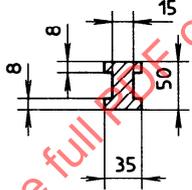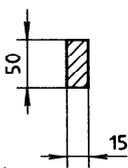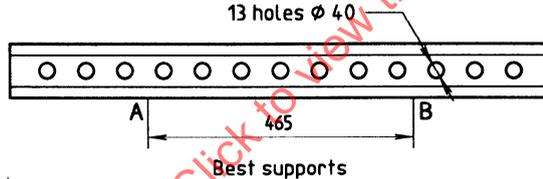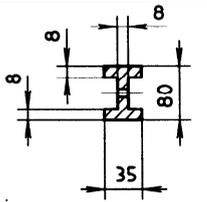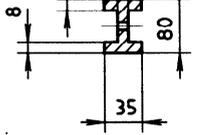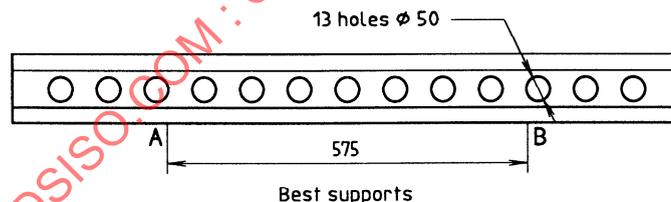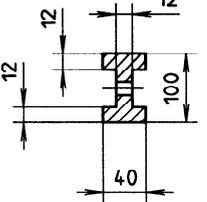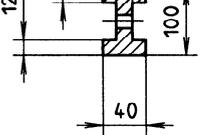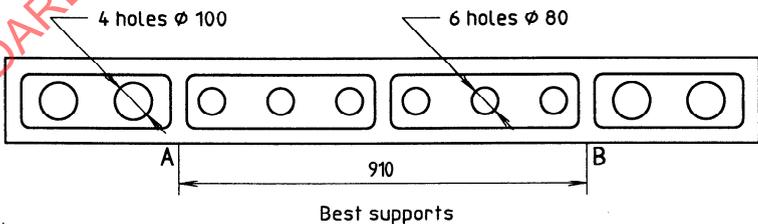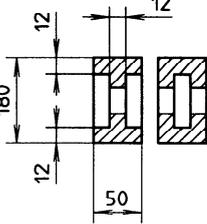
1) The total length is a little greater than the working length, so that inspections may be made without having to use the ends of the straightedge, which are more difficult to machine accurately.

2) Masses are relative to plain cast iron; they would be slightly greater in the case of steel.

**Table A.2— Accuracy requirements corresponding to the five straightedges in table A.1**

| No. | Dimensions | Deflection with supports at extreme end in the case of plain cast iron[1] | Working faces | | Side faces | | |
|---|---|---|---|---|---|---|---|
| | | | Straightness[2] | Parallelism | Straightness | Parallelism | Squareness or perpendicularity to working faces |
| 1 | 300 Normal 300 Broad | 0,001 | 0,005 | 0,007 5 | 0,050 | 0,075 | ± 0,008 |
| 2 | 500 Normal 500 Broad | 0,003 | 0,007 | 0,010 5 | 0,070 | 0,105 | ± 0,012 |
| 3 | 800 | 0,004 | 0,010 | 0,015 0 | 0,100 | 0,150 | ± 0,020 |
| 4 | 1 000 | 0,008 | 0,012 | 0,018 0 | 0,120 | 0,180 | ± 0,025 |
| 5 | 1 600 | 0,016 | 0,018 | 0,027 0 | 0,180 | 0,270 | ± 0,045 |

1) $E = 98$ kN/mm$^2$

2) Local tolerance = 0,005 mm over 300 mm.

## A.3.1 Description

Test mandrels have a tapered shank for inserting in the socket of the machine to be tested, and a cylindrical body which is used as a reference for the measurements [see figure A.2 a) and b)]. They are made of hardened and stabilized steel, either unplated or plated with hard chromium.

They also have the following characteristics:

a) ground and lapped centres, recessed for protection at the ends, for purposes of manufacture and inspection;

b) four reference lines r spaced at 90° (1, 2, 3 and 4); the distance between the marks at the two ends of the cylindrical part represents the measuring length $l$: 75 mm, 150 mm, 200 mm, 300 mm or 500 mm;

c) in the case of relatively slow Morse and metric tapers, the mandrels are self-holding in the socket [see figure A.2 a)]. A threaded portion is provided to receive a nut for extracting the mandrel from the socket;

d) in the case of relatively steep tapers [see figure A.2 b)], a tapped hole is provided for fixing the mandrel by means of a threaded retaining bar, or a retention knob as used with an automatic tool-changing device [see figure A.2 c)].

Finally, in order to avoid the mandrel being reversed end for end when grinding, the instrument may also be fitted with an extension $P$ of a length from 14 mm to 32 mm and a diameter slightly smaller than that of the cylindrical part [see figure A.2 d)].

Figure A.3 shows, as examples, a series of suitable mandrels. The external dimensions (diameter and length) and the profile of the bore of these mandrels have been determined so that (with the exception of those with Morse tapers No. 0 and No. 1) the deflection at the free end, due to the overhanging weight of the mandrel and the deflection caused by the pressure of a dial gauge upon it, are negligible when testing with these instruments.

Table A.3 gives the values of the deflections. These deflections have been calculated for $E = 206$ kN/mm$^2$; even for somewhat smaller values ($E = 176$ kN/mm$^2$ to 186 kN/mm$^2$) the deflections are still negligible.

In the case of the 7/24 taper, table A.4 indicates the correspondence between the cylindrical portions and the dimensions of the cone.

If the mandrels with dimensions differing from those in figure A.3 are used for checking alignment, their deflection should be distinctly marked on them and taken into account when testing machines.

Finally, attention is drawn to the fact that mandrels above 5 kg in mass tend to cause deflection of the spindle into which they are inserted.

## A.3.2 Accuracy

Mandrels should meet the requirements given in tables A.3, A.4 and A.5.

In order to obtain a good fit in machine sockets, the accuracy of the taper shanks should correspond to that of taper plug gauges.
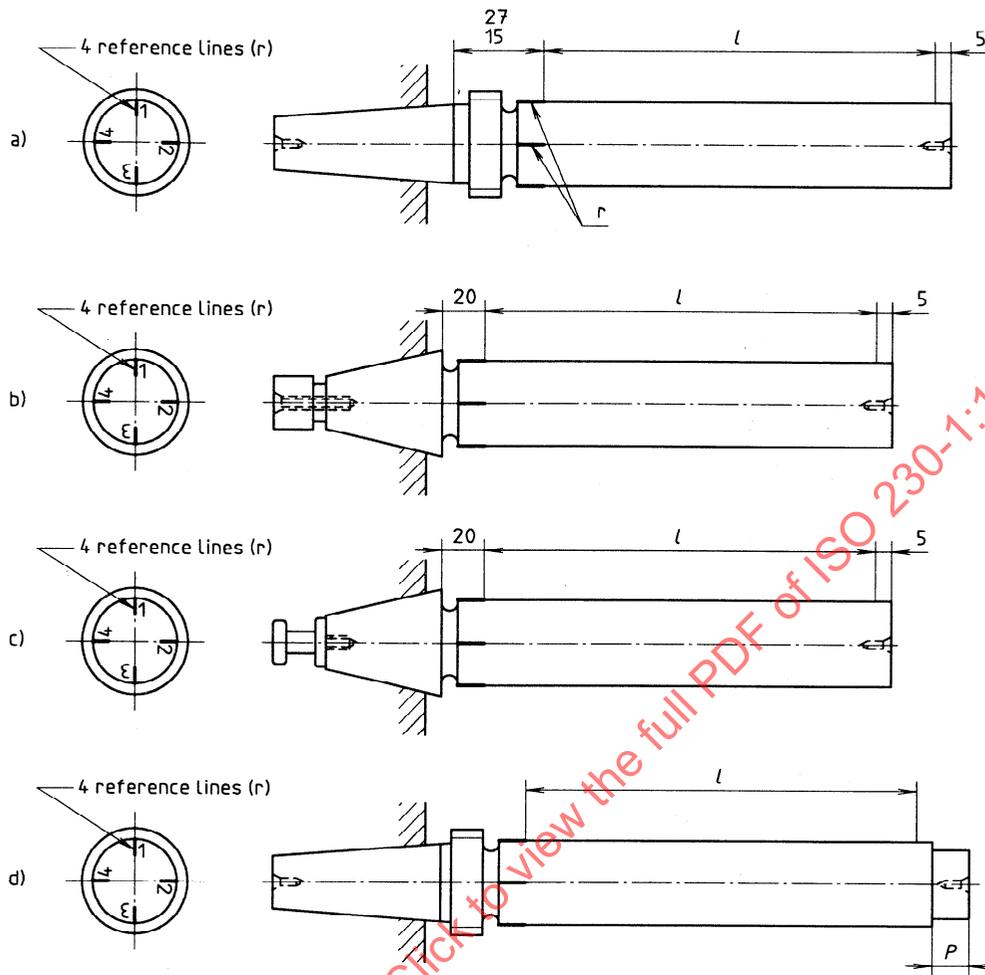
Dimensions in millimetres



**Figure A.2 —The mandrels of Morse and metric tapers**

**Table A.3 — Test mandrels — Deflection values**

| No. of taper | Working length | Mandrels without extension Type A | | | | | Mandrels with extension Type C | | | | | Obser-vations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Approxi-mate total mass | Natural deflec-tion[1] | Additional deflection under load $P$ acting on free end | | Total deflec-tion | Approxi-mate total mass | Natural deflec-tion[1] | Additional deflection under load $P$ acting on free end | | Total deflec-tion | |
| | | | | $P$ | | | | | $P$ | | | |
| | mm | kg | mm | g | mm | mm | kg | mm | g | mm | mm | |
| Morse 0 | 75 | 0,11 | 0,000 65 | 50 | 0,000 9 | 0,001 6 | 0,12 | 0,000 9 | 50 | 0,000 9 | 0,001 8 | Deflections shall be taken into account |
| Morse 1 | 75 | 0,13 | 0,000 5 | 50 | 0,000 7 | 0,001 2 | 0,14 | 0,000 7 | 50 | 0,000 7 | 0,001 4 | |
| Morse 2 | 150 | 0,73 | 0,001 5 | 100 | 0,000 6 | 0,002 1 | 0,79 | 0,001 9 | 100 | 0,000 6 | 0,002 5 | |
| Morse 3 | 200 | 0,96 | 0,001 8 | 100 | 0,000 7 | 0,002 5 | 1,09 | 0,002 2 | 100 | 0,000 7 | 0,002 9 | |
| Morse 4 | 300 | 2,2 | 0,003 3 | 100 | 0,000 7 | 0,004 | 2,28 | 0,003 9 | 100 | 0,000 7 | 0,004 6 | Deflections are negligible |
| Morse 5 | 300 | 3 | 0,002 6 | 100 | 0,000 6 | 0,003 2 | 3,14 | 0,003 1 | 100 | 0,000 6 | 0,003 7 | |
| Morse 6 | 500 | 10 | 0,005 8 | 100 | 0,000 35 | 0,006 2 | 10,32 | 0,006 6 | 100 | 0,000 35 | 0,007 | |
| Metric 80 and larger | 500 | 15 | 0,003 5 | 100 | 0,000 15 | 0,003 7 | 15,24 | 0,003 9 | 100 | 0,000 15 | 0,004 1 | |

1) The figures shown correspond to the difference in natural deflection at the two ends of the measurement length.