
British Standard

General tests for machine tools

Part 1. Code of practice for testing
geometric accuracy of machines operating
under no load or finishing conditions

Essais généraux des machines-outils

Partie 1. Code de bonne pratique du contrôle de la précision géométrique des machines
travaillant à vide ou dans des conditions de finition

Prüfung von Werkzeugmaschinen

Teil 1. Leitfaden für die Prüfung der geometrischen Genauigkeit von Maschinen im
unbelasteten Zustand und unter Fertigungsbedingungen

Foreword

This Part of BS 3800 has been prepared under the direction of the Machine, Engineers and Hand Tools Standards Policy Committee and supersedes BS 3800 : 1964 which is withdrawn. It is based on related but not completed work of ISO/TC 39, Machine Tools, of the International Organization for Standardization (ISO).

Other Parts of BS 3800 will deal with statistical methods, performance, vibration and noise.

Prior to commencing tests on machines in an operational condition, it is important that appropriate safety precautions are taken to comply with the Health and Safety at Work etc. Act 1974 and to ensure that no person is exposed to danger. Manufacturers have a duty to ensure that, so far as is reasonably practicable, their machines are designed and constructed to be safe when properly used. Also manufacturers should provide appropriate information and instruction on safety in their machine manuals. General guidance on machinery safety is given in BS 5304.

Compliance with a British Standard does not of itself confer immunity from legal obligations.



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General tests for machine tools
Part 1. Code of practice for testing geometric
accuracy of machines operating under no load or
finishing conditions

Correction

AMD 6616
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Clause A.3.2 Accuracy

In item (a), delete the existing formula and substitute the formula:

$$\frac{(2 + 0.01 L)}{1000} \text{ mm}$$

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0 Introduction

The aim of this Part of BS 3800 is to standardize methods of testing the accuracy of all types of machine tool by means of geometrical and practical tests.

This Part of BS 3800 relates only to testing of accuracy. In particular, it deals neither with the checking of the running of the machine tool, e.g. vibrations, abnormal noises, slip and stick motion of components, nor with the checking of characteristics, e.g. speeds, feeds.

When a measurement procedure 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.

After general considerations on definitions, testing methods, use of checking instruments and tolerances, this Part deals with preliminary checking operations, practical tests, and geometrical checks, as well as some special checks. Appendix A provides information about equipment used for testing.

Definitions. Definitions of specific terms are given in the clause or subclause to which they refer.

Practical tests consist of machining test pieces appropriate to the fundamental purposes for which the machine has been designed, and having predetermined dimensions and tolerances (see 4.1).

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

The clause numbering of the 1964 edition has been retained in the main text as far as possible. In order to facilitate cross referencing in those cases where numbers have changed, appendix B lists the old clause numbers and the new equivalents.

1 Scope

This Part of BS 3800 gives recommendations on methods of testing the accuracy of machine tools by means of geometrical and practical tests. It provides information on definitions, testing methods, use of checking instruments and tolerances, and describes preliminary checking operations and geometrical checks as well as some special checks. Appendix A deals with the accuracy of instruments used for testing machine tools.

NOTE. The titles of the publications referred to in this standard are listed on the inside back cover.

2 General considerations

2.0 Definition

For the purposes of this Part of BS 3800 the following definition applies.

Metalworking machine tool. A power driven machine, not portable by hand while in operation, which works metal by cutting, forming, physico/chemical processing, or a combination of these techniques.

2.1 Definitions relating to geometrical checks

A distinction should be made between geometrical definitions and those designated in this standard as metrological definitions.

Geometrical definitions are abstract and relate only to imaginary lines and surfaces. From this it follows that geometrical definitions sometimes cannot be applied in practice. They take no account of the realities of construction or the possibility of checking. However, in some cases, geometrical definitions, e.g. definitions of out-of-true running, periodical axial slip, etc., have been retained in the standard in order to eliminate any confusion and to clarify the language used but, when describing testing methods, measuring instruments and tolerances, metrological definitions are taken as a basis.

Metrological definitions are real, as they take account of lines and surfaces accessible to measurement. They cover in a single result all micro- and macro-geometrical errors. They allow a result to be reached covering all causes of error, without distinguishing them from one another. This distinction should be left to the manufacturers. Metrological definitions are taken as a basis when describing testing methods, measuring instruments and tolerances.

2.2 Testing methods and use of checking instruments

During the testing of a machine tool, the methods of measurement may only allow verification that the tolerances are not exceeded, e.g. limit gauges, or it may only be possible to determine the actual deviations by high precision measurements for which a great amount of time would be required. In such cases it is sufficient, instead of measuring, to check that the limits of the tolerance are not exceeded.

It should be emphasized that errors of measurement due to the instruments, as well as to the methods used, are to be taken into consideration during the tests. The measuring instrument should not give any error of measurement exceeding a known 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 furnished with each instrument.

Testing operations should be protected from draughts and from disturbing heat radiations, e.g. sunlight, electric lamps too close, and the temperature of the measuring instruments should be stabilized before measuring. The machine itself should be suitably protected from the effects of external temperature variations.

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

2.3 Tolerances

2.31¹ Tolerances on measurements when testing machine tools

2.310 General. 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.

Tolerances may also apply to test pieces only.

2.311 Units of measurement, measuring ranges. When establishing tolerances, it is necessary to indicate:

- (a) the unit of measurement used;
- (b) the nominal (or reference base) value and the magnitude of its tolerance(s);
- (c) the range over which measurement is made.

The tolerance and the measuring range should be expressed in the same unit system. Tolerances, particularly tolerances on sizes, should be indicated only when it is impossible to define them by simple reference to British Standards for machine tool elements. Those relating to angles should be expressed either in units of angle, i.e. degree, minute, second or as tangents (mm per m).

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

2.312 Rules concerning tolerances. Tolerances include errors inherent in the measuring instruments and test methods used. Errors of measurement should consequently be taken into account in the permitted tolerances (see 2.2).

Example.

Tolerances 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 of block gauges, reference discs, etc., inaccuracies arising from comparative laboratory measurements, and inaccuracies of form of machine parts used as reference surfaces, including surfaces masked by styli or by support points of measuring instruments, should be neglected.

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

Lines or surfaces chosen as reference bases should be directly related to the machine tool, e.g. line between centres of a lathe, spindle of a boring machine, slideways

of a planing machine, etc. The direction of the tolerance should be in accordance with the definitions given in 2.325.

2.32 Subdivisions of tolerances

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

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

For internal and external dimensions of cylindrical and parallelepipedic parts, tolerances should be given in accordance with the rules given in BS 308 : Part 2. Tolerances should be indicated by stating the maximum material condition and the deviation or by giving the basic size and the limits in the symbols of BS 4500 : Part 1, e.g. 40 E5 or 40 E8.

2.321.2 Tolerances of form. Tolerances of form limit the permissible deviations from the theoretical geometric form, e.g. deviations relative to a plane, to a straight line, to a revolving cylinder, to the profile of thread or of tooth. They are 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 should be stated.

The stylus surface should be generally proportional to the precision and to the dimension of the surface to be checked; a surface plate and the table of a heavy planing machine, for example, are not checked from the same stylus surface.

NOTE. Rules for indicating geometrical tolerances on drawings are given in BS 308 : Part 3 which enable the geometrical accuracy of individual parts to be specified. These rules should be adhered to on manufacturing drawings.

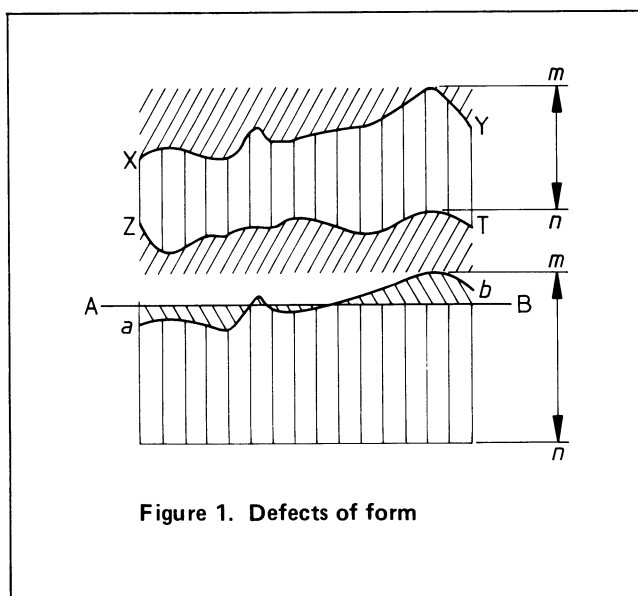
2.321.3 Tolerances of position. Tolerances of position limit the permissible deviations concerning the position of an element relative to a line, to a plane, or to another element of the machine, e.g. deviation of parallelism, of perpendicularity, of alignment, etc. They are expressed in units of length 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 in the same way the working accuracy of the machine tool.

NOTE 1. When a position is determined in relation to surfaces showing errors of form, these errors of form should be taken into account when fixing the tolerance of position.

NOTE 2. Rules for indicating geometrical tolerances on drawings are given in BS 308 : Part 3 which enable the geometrical accuracy of individual parts to be specified. These rules should be adhered to on manufacturing drawings.

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



When setting out on a graph (see figure 1) the different readings mn of the checking instrument, a curve such as ab is obtained. The error is to be determined by using line AB as determined in accordance with 5.211.1.

2.322 Tolerances applicable to the displacement of an element of a machine tool

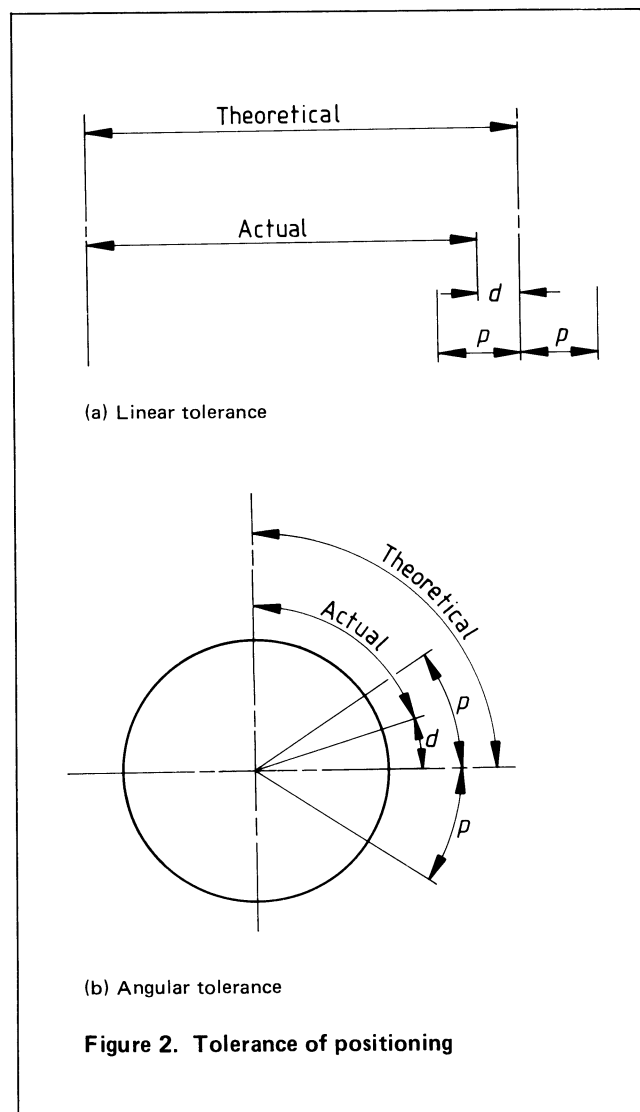
2.322.1 Tolerances of positioning and repeatability

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

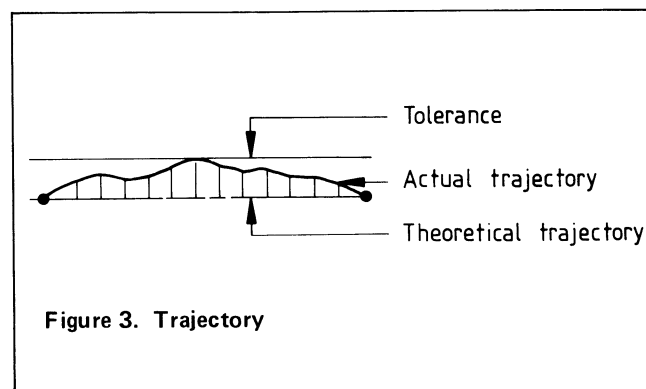
Example 1. At the end of the travel of a slide, the deviation d is the distance between the actual position and the position it should have reached under the action of its drive. The tolerance of positioning is p (see figure 2(a)).

Example 2. Angle of rotation of a spindle relative to the angular displacement of a dividing plate coupled to it (see figure 2(b)).

2.322.1.2 Tolerances of repeatability. Tolerances of repeatability limit the error to a given value when repeating movements approach the target in the same or either direction.



2.322.2 Tolerances of form of trajectory. Tolerances of form of trajectory limit the deviation of the actual trajectory of a point relative to the theoretical trajectory (see figure 3). They should be stated in units of length.



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

2.322.4 Local tolerances. Tolerances of form and position are usually relative to the form or position as a whole, e.g. 0.03 per 1000 for a straightness or flatness. However, it

may be desirable to limit the permissible deviation over a short length to a different value. This is achieved by establishing a local tolerance related to an element of the total length (see figure 5(a)).

The local deviation is the distance between two lines parallel to the general direction of trajectory of the element which contains the maximum deviations of the short length.

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

- (a) from the British Standard relating to a machine tool and for each particular test; or
- (b) as a proportion of the total tolerance ($T_{\max.}$), provided that it does not fall below a minimum value (normally 0.001 mm) (see figure 5(b)), in accordance with the following equation:

$$T_{\min.} = \frac{T_{\max.}}{L_2} \times L_1$$

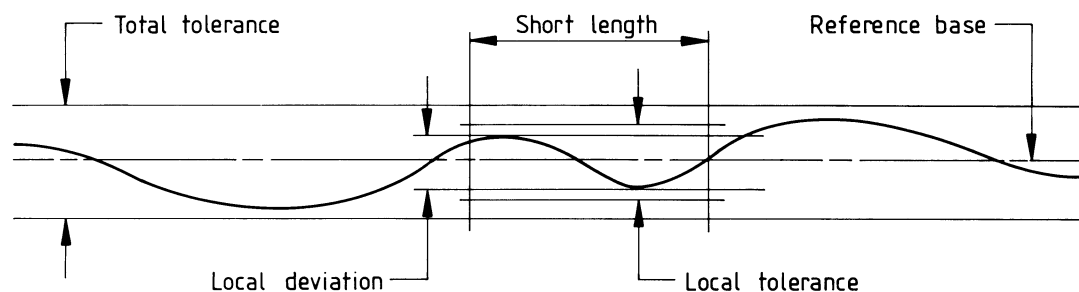
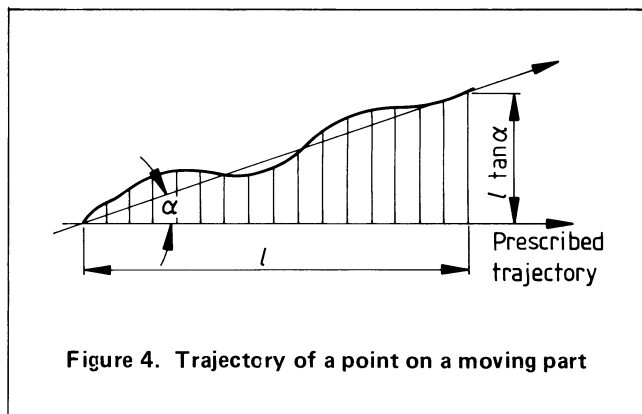
Example.

$$T_{\max.} = 0.030 \text{ mm}$$

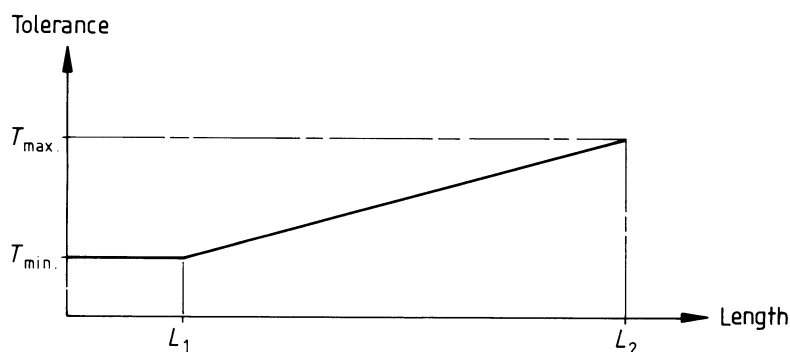
$$L_2 = 1000 \text{ mm}$$

$$L_1 = 100 \text{ mm}$$

$$\begin{aligned} \text{Then } T_{\min.} &= \frac{0.030}{1000} \times 100 \\ &= 0.003 \text{ mm} \end{aligned}$$



(a)



(b)

Figure 5. Local deviation

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, e.g. styli of dial gauges or micro-indicators, the measuring device should be such that the styli follow a surface of high grade finish, e.g. straight-edge, test mandrel, etc.

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

Example (see figure 6). The deviation for run-out of a shaft is the sum of the deviations of form (out-of-round of the circumference on which the plunger is in contact), the deviations of position (the geometrical axis of the shaft and

its axis of rotation do not coincide) and the out-of-round deviation of the bearing.

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 should be stated precisely in words in relation to, either:

- (a) the machine or one of the components of the machine; or
- (b) the operator.

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 displacement and rotations of the machine parts are designated by letters, e.g. X, Y, Z, and signs, in accordance with ISO 841.

X, Y and Z define axes and A, B and C define rotary motions about these axes (see figure 7(a)).

When considering the movement of a tool, positive A, B and C rotations are in directions to advance right-hand screws in positive X, Y and Z directions respectively. If however, the movement of a workpiece is being considered, the positive direction of movement is in the opposite sense. In schematic drawings, the difference is indicated by using a 'primed' letter for a workpiece movement, e.g. C' in figure 7(b). Secondary displacement axes are designated by the letters U, V and W as required.

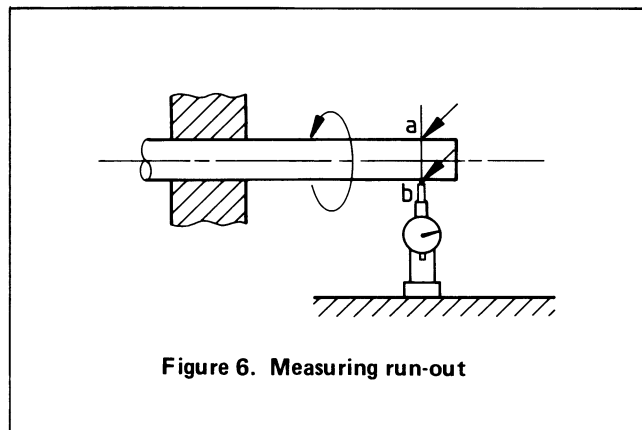
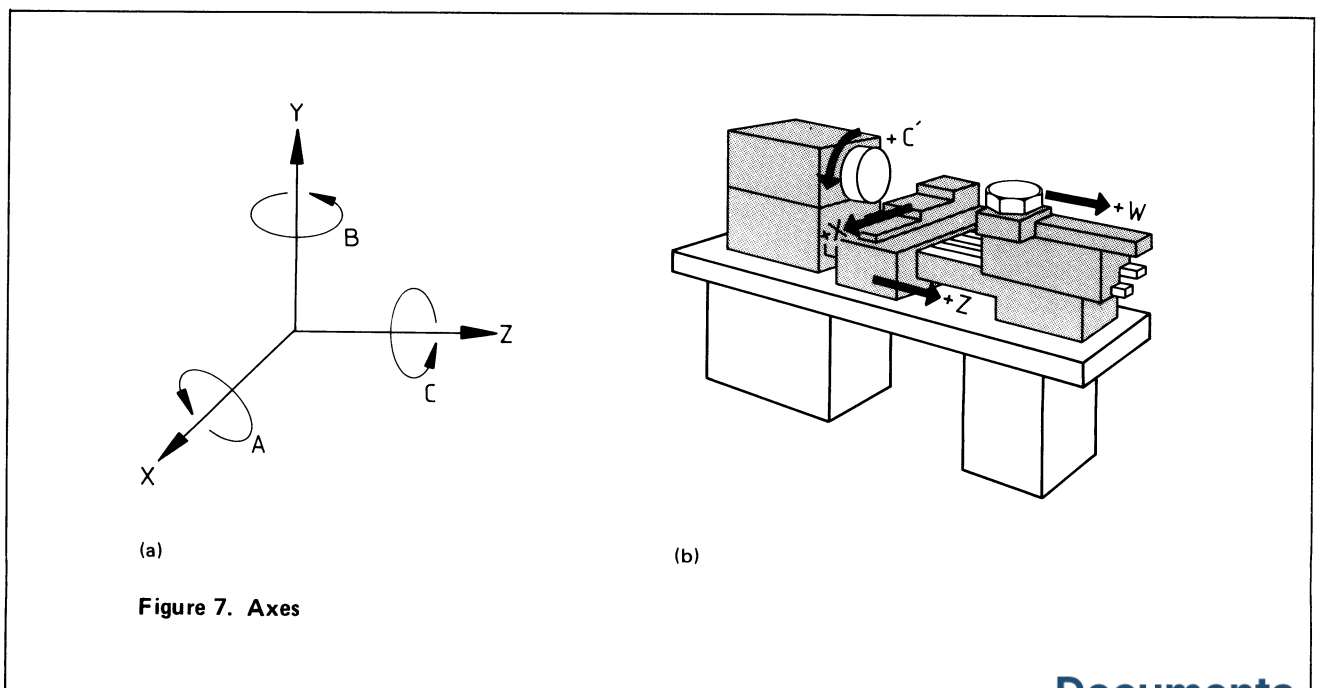


Figure 6. Measuring run-out



(a)

(b)

Figure 7. Axes

3 Preliminary checking operations

3.1 Installation and levelling of the machine before testing

Prior to testing a machine tool, it is essential that it is installed and levelled in accordance with the manufacturer's instructions.

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 parts.

3.2 Condition of the machine before testing

3.21 Dismantling of certain elements. As the tests are carried out, in principle, on a completely finished machine, dismantling of certain elements 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 before testing. During the geometrical and practical tests, elements, e.g. spindles which are liable to warm up and consequently to change position or shape, should be brought up to the correct temperature by running the machine idle in accordance with the conditions of use and the instructions of the manufacturer.

Special conditions apply to numerically controlled machines, when temperature fluctuations may have a marked effect on the accuracy.

It is necessary to consider how much the machine alters in dimension during a normal working cycle from ambient to working temperature. The 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 should be considered 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 leadscrew.

3.23 Functioning and loading. Geometrical checks are made either when the machine is at a standstill or when it is running idle. When specified by the manufacturer, e.g. in the case of heavy-duty machines, the machine should be loaded with one or more workpieces or tools.

4 Practical tests

4.1 Testing

Practical tests should be carried out on standard test pieces or test pieces supplied by the user, the making of which does not require operations other than those for which the machine has been built. Practical tests to ascertain the

precision of a machine tool should be the finishing operations for which the machine has been designed.

NOTE. It is essential that such tests should be carried out in good faith.

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

The nature of the workpieces to be made, their dimensions, their material and the degree of accuracy to be obtained and the cutting conditions should be the subject of agreement between the manufacturer and the user, unless relevant British Standards already exist.

4.2 Checking of workpieces in practical tests

Checking of workpieces in practical tests should be done with 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 verifications.

4.3 Importance of practical tests

The results of practical tests and geometrical checks can be compared only in so far as these two kinds of tests have the same object.

In certain cases, the practical tests may be replaced or supplemented by a special test defined in the corresponding British Standard, e.g. deflection test under load, kinematic test.

5 Geometrical checks

5.1 General

This clause gives a definition*, a method of measurement and the way of determining the tolerance for each geometrical check of a given characteristic of shape, position or displacement of lines or surfaces of the machine as follows:

- (a) straightness (see **5.2**);
- (b) flatness (see **5.3**);
- (c) parallelism, equidistance and coincidence (see **5.4**);
- (d) squareness (see **5.5**);
- (e) rotations (see **5.6**);
- (f) accuracy and repeatability of numerically controlled (NC) machine tools (see BS 4656 : Part 16).

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

When other methods of measurement are used, their accuracy should be at least equal to the accuracy of those stated in this standard.

* See also **2.1**.

5.2 Straightness

5.20 General. Geometrical checks covering straightness are the following:

- (a) straightness of a line in a plane or in space (see 5.21);
- (b) straightness of elements (see 5.22);
- (c) straight line motion (see 5.23).

5.21 Straightness of a line in a plane or in space

5.211 Definitions

5.211.1 straightness of a line in a plane (see figure 8(a)).

A line located in a plane is straight over a given length when all its points are contained between two straight lines parallel to the general direction of the line, whose distance apart is equal to the tolerance (see BS 308 : Part 2).

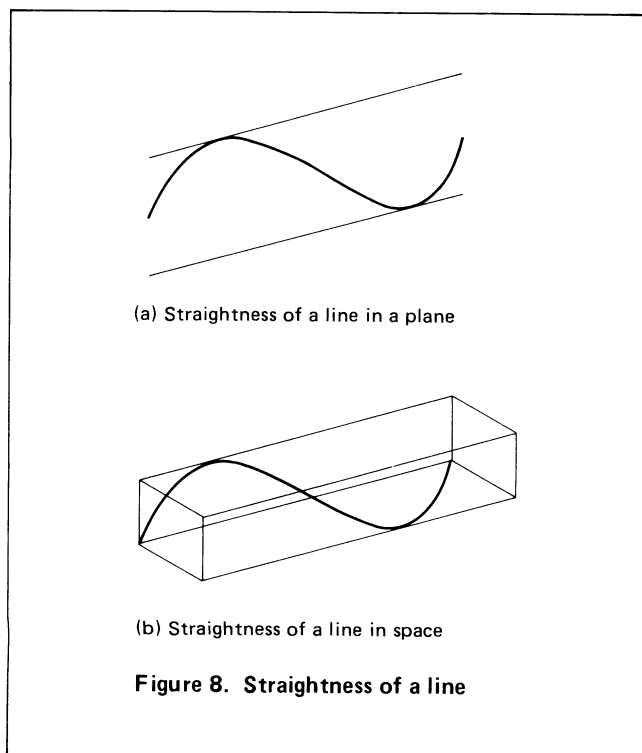
NOTE. The general direction of the line or 'reference line' should be determined so as to minimize the straightness deviation but it may be conventionally determined as follows either:

- (a) by two points appropriately chosen near the ends of the line to be checked (in most cases parts very close to the ends can be neglected as they most often present small insignificant local defects); or
- (b) by a straight line computed from plotted points, e.g. least square method to minimize the distance between the two lines parallel to the general direction of the line.

5.211.2 straightness of a line in space (see figure 8(b)).

A line in space is 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).

NOTE. The tolerance can be different in each plane.



5.212 Methods of measurement

5.212.0 General. There are two methods of measurement based on either:

- (a) measurements with linear instruments; or
- (b) measurements with angular instruments.

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

It is recommended to use:

- (1) for lengths below 1600 mm: a precision level or physical reference, e.g. a straightedge;
- (2) for lengths above 1600 mm: reference lines (by means of a precision level, optical devices or possibly a taut-wire).

5.212.1 Methods based on the measurement of dimensional deviations

5.212.11 General. Whatever the type of the practical reference being used, this should be placed with respect to the line to be checked in a relative position referred to as the reference of measurement (or initial straight line of reference *amb* (see figure 9)).

The instrument provides readings of any deviation of the checked line with respect to the reference of measurement; readings may be obtained at various points (regularly distributed or not) over the whole length of the checked line, selected point spacing being independent of the instruments used.

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

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

The straightness deviation is the distance between two straight lines parallel to the reference line touching the upper and lower points of deviation.

5.212.12 Straightedge method of measurement in a vertical plane. The straightedge is placed on two blocks, located, if possible, at the points corresponding to the minimum deflections due to its own gravity (Airy points).

The measurement is made by moving along the straightedge a rider of which one point rests on the surface to be measured and the other carries a dial gauge, the stylus of which is in contact with the straightedge (see figure 10).

NOTE. Provision should be made for the moving element to follow a straight line (guiding straightedge).

The rider should be so designed that the dial gauge stylus is situated on the normal line to the surface to be checked. Known errors of the straightedge can be taken into account, if required, in processing the result.

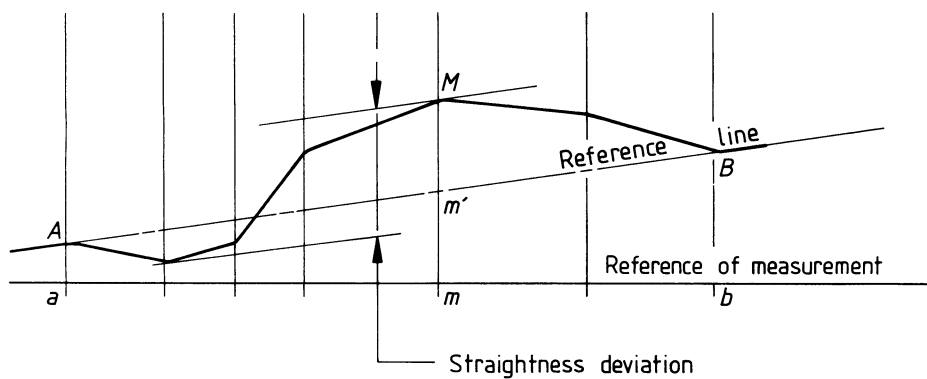


Figure 9. Dimensional deviations

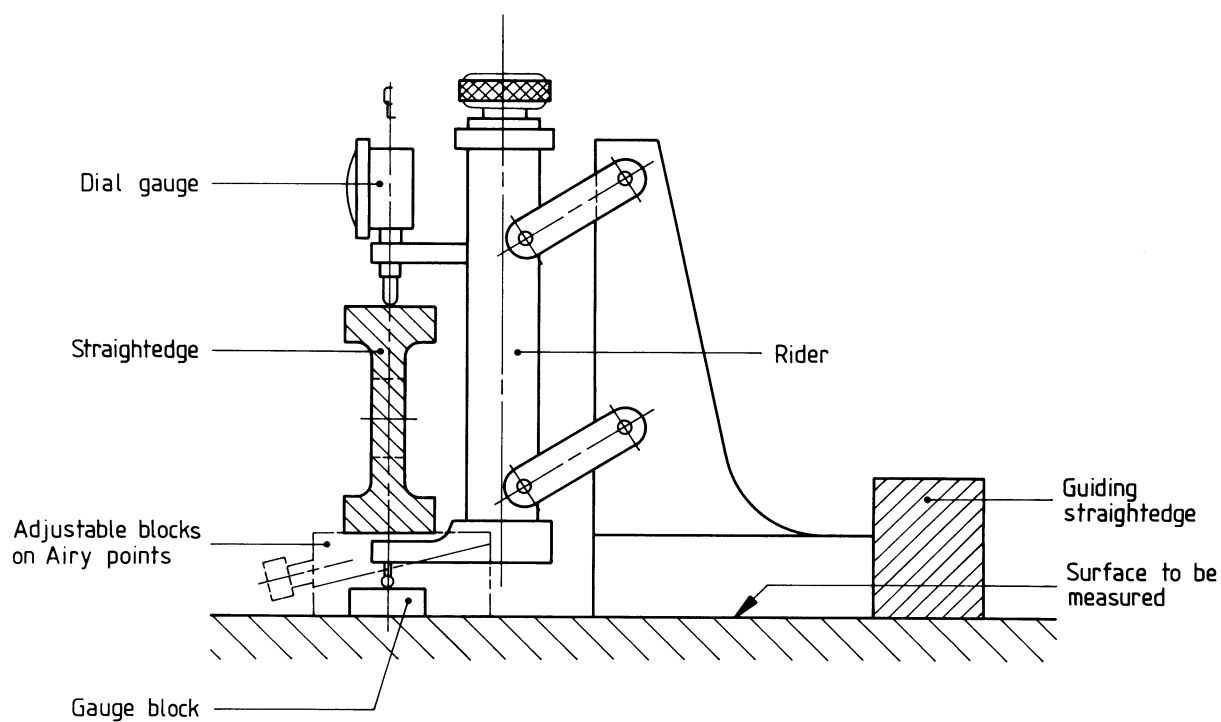


Figure 10. Vertical plane measurement

5.212.13 Straightedge method of measurement in a horizontal plane. In this case it is advisable to use a parallel face straightedge lying flat.

The reference face is touched by a dial gauge moving in contact with the surface to be checked (see figure 11).

The straightedge is set to give identical readings at both ends of the line; errors in the line relative to the straight line joining the two extremes may be read off directly.

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 the straightness errors of both the surface and of the straightedge reference face 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.

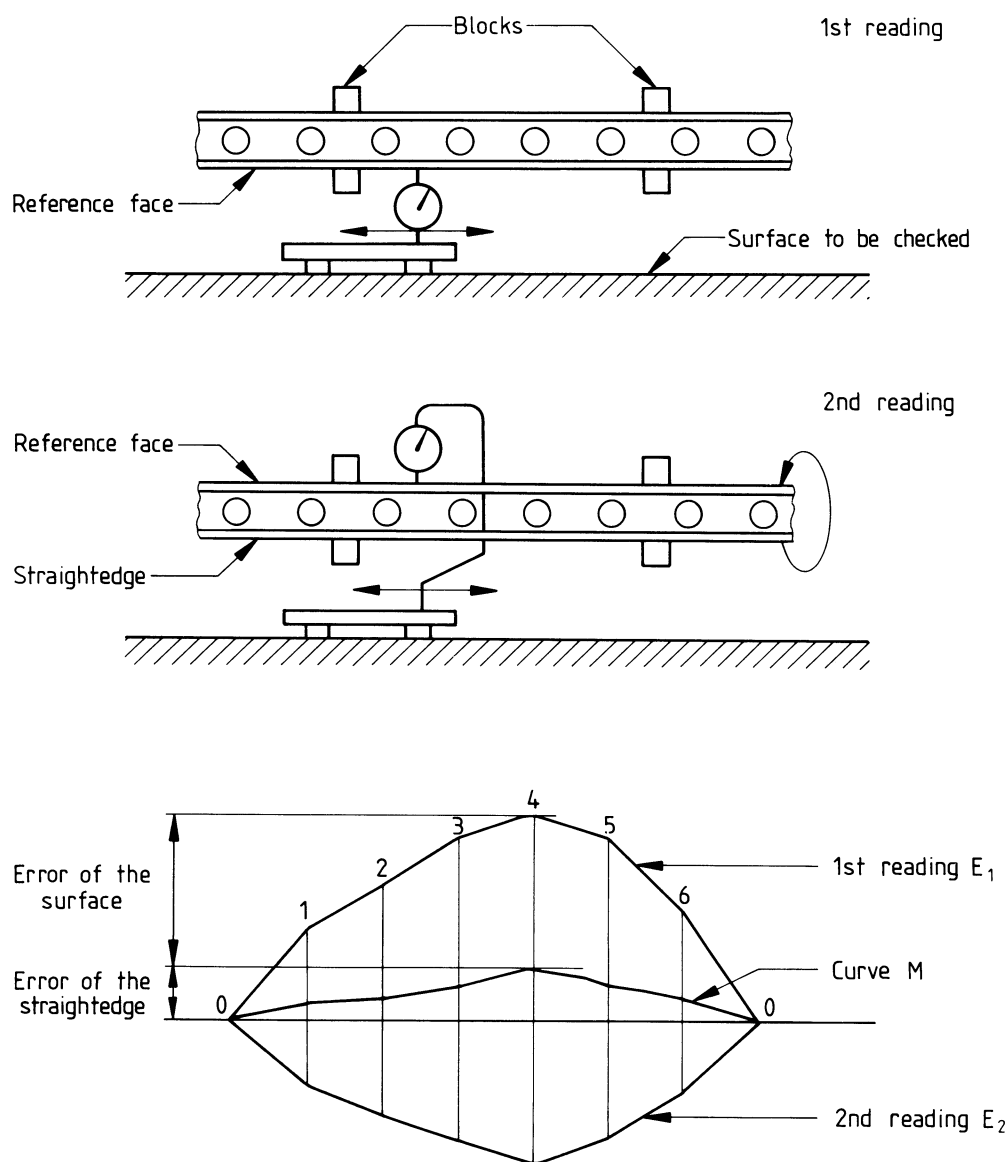


Figure 11. Horizontal plane measurement

Both error curves E_1 and E_2 thus obtained and compared on figure 11 are the sum of the straightedge and surface errors on the one hand and the difference of those errors on the other hand.

The average curve M is the error of the reference face of the straightedge R . Deviation $E_1 - M$ (or $E_2 - M$ which is equal) is the straightness error of the checked surface.

5.212.14 Taut-wire and microscope method. A thin wire of a constant diameter is stretched in order to be approximately parallel to the line to be checked (see figure 12). 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 A.11).

NOTE 1. The taut-wire F and the line to be checked are to be in the same plane perpendicular to the considered surface containing MN .

NOTE 2. The microscope support rests on the surface containing the line to be checked in two points, of which one is situated in the plane normal to the surface considered containing the microscope optical axis (see figure 12).

NOTE 3. 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 12 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.

5.212.15 Alignment telescope method. Using an alignment telescope, the measurement of 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 according to the instrument used (see figure 13 and A.13).

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

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

One of the target support points P should be placed on the line to be checked and treated with all precautions as described in 5.212.12 and 5.212.13.

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

All precautions should 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.

NOTE. The target support should rest on the surface containing the line to be checked in as many points as required to measure its stability and guiding.

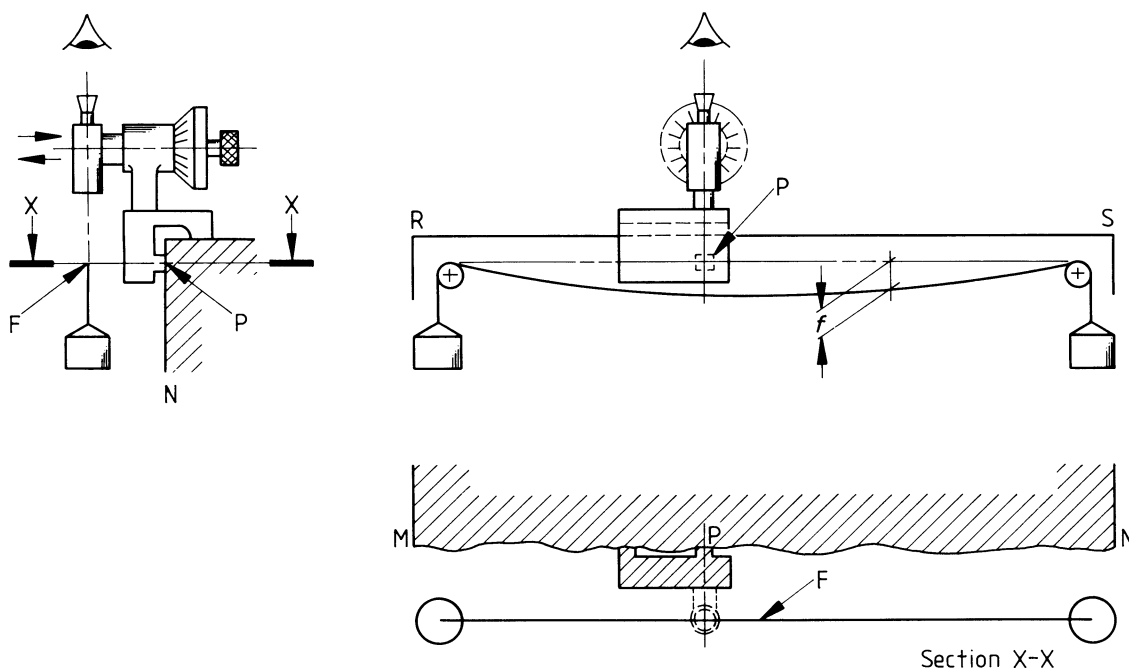


Figure 12. Taut wire and microscope

5.212.16 Laser techniques

5.212.161 Alignment laser technique (see figure 14(a)). A laser beam is used as a straight line reference. 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.9**).

5.212.162 Laser interferometry technique (see figure 14(b)). A laser beam is used as a straight line reference.

A laser interferometer and special optical components are used to detect changes in the position of a target relative to the axis of a laser beam. The optical components and precise measuring methods vary and the manufacturer's instructions should be consulted (see also **A.9**).

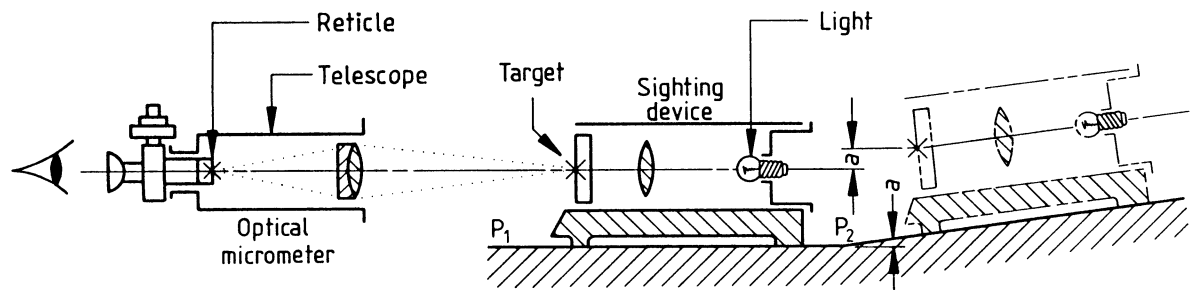


Figure 13. Alignment telescope

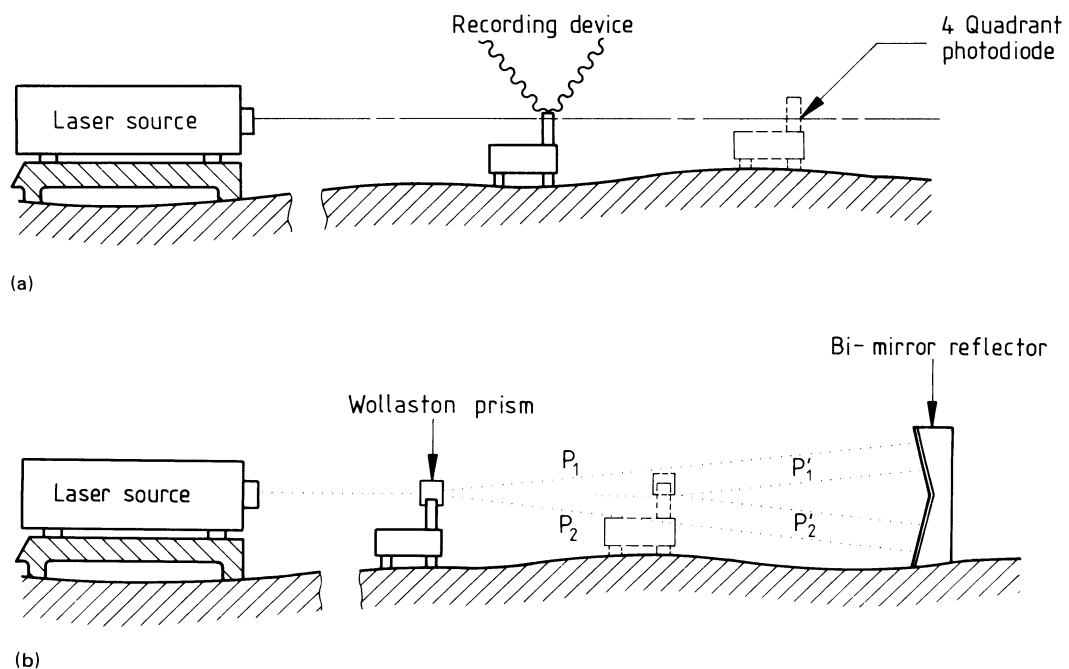


Figure 14. Lasers

5.212.2 Methods based on the measurement of angular deviations

5.212.20 General. In these methods a moving element is in contact with the line to be checked in two points P and Q separated by a distance d (see figure 15). The moving element is displaced in such a way that in two successive positions P_1Q_1 and P_2Q_2 , P_2 is coincident with Q_1 . With an instrument placed in a plane perpendicular to the surface containing the line to be checked, the angles α_1 and α_2 of the moving element relative to a reference of measurement are measured.

Results are processed as follows (see figure 16). The following parameters are plotted graphically with appropriate scales:

- (a) in abscissae, the various distances d corresponding to the checking line;
- (b) in ordinates, the relative differences of level with respect to the reference of measurement. The relative level difference is calculated as follows:

$$\Delta h_{n-1} = d \cdot \tan \alpha_i$$

The various points $P_0P_1P_2 \dots P_i \dots P_n$ of the checked line can be located with the desired scale magnification.

The reference line is defined from the line itself by the extremes P_0P_n .

The straightness deviation is defined as in 5.212.11 by the distance along the Y'Y axis between two straight lines parallel to the reference line touching the curve at its higher and lower points.

NOTE 1. 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.

NOTE 2. These methods can also be applied over long distances but in this case the value d should be chosen so that a large number of readings and accumulating errors can be avoided.

5.212.21 Precision level method. The measuring element is a precision level (see A.4) which is positioned successively along the line to be checked as explained in 5.212.20. The reference of measurement is the horizontal level of the instrument which measures small angles in the vertical plane

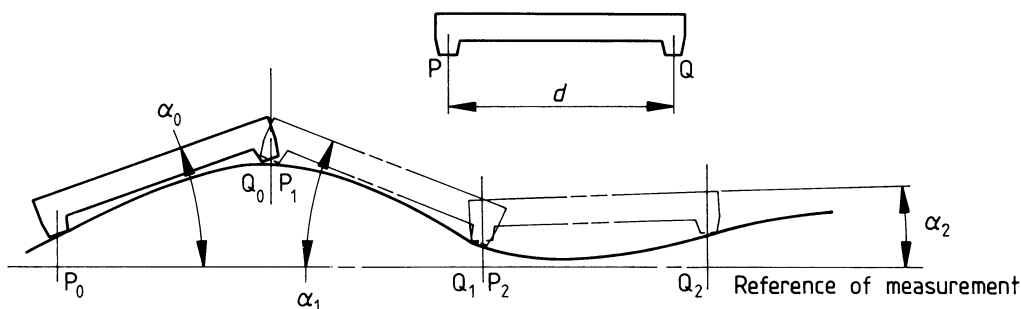


Figure 15. Angular deviations

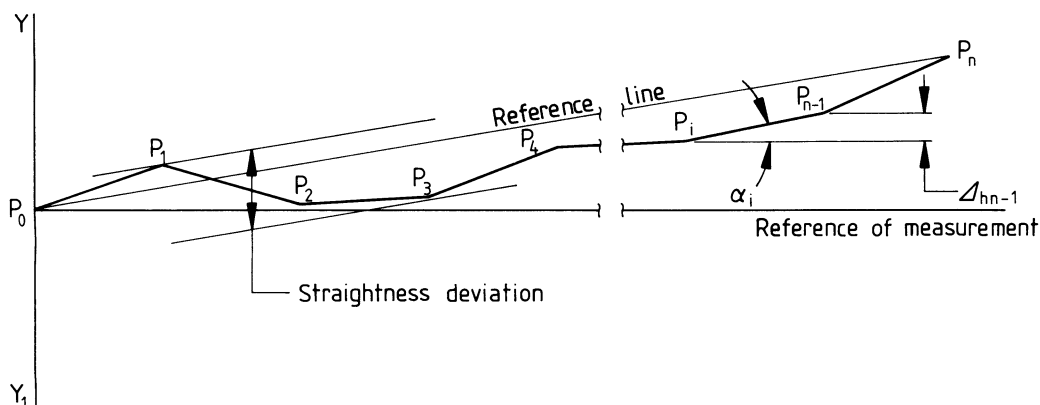
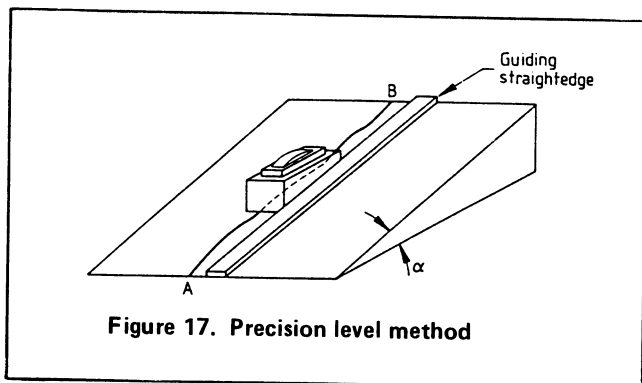


Figure 16. Plot of results of angular deviations

(see figure 15). If the line to be measured is not reasonably horizontal the level is mounted on a suitable angled support block (see figure 17).

NOTE 1. While checking line AB, the level together with its support should keep a constant orientation, e.g. by means of a guiding straightedge.



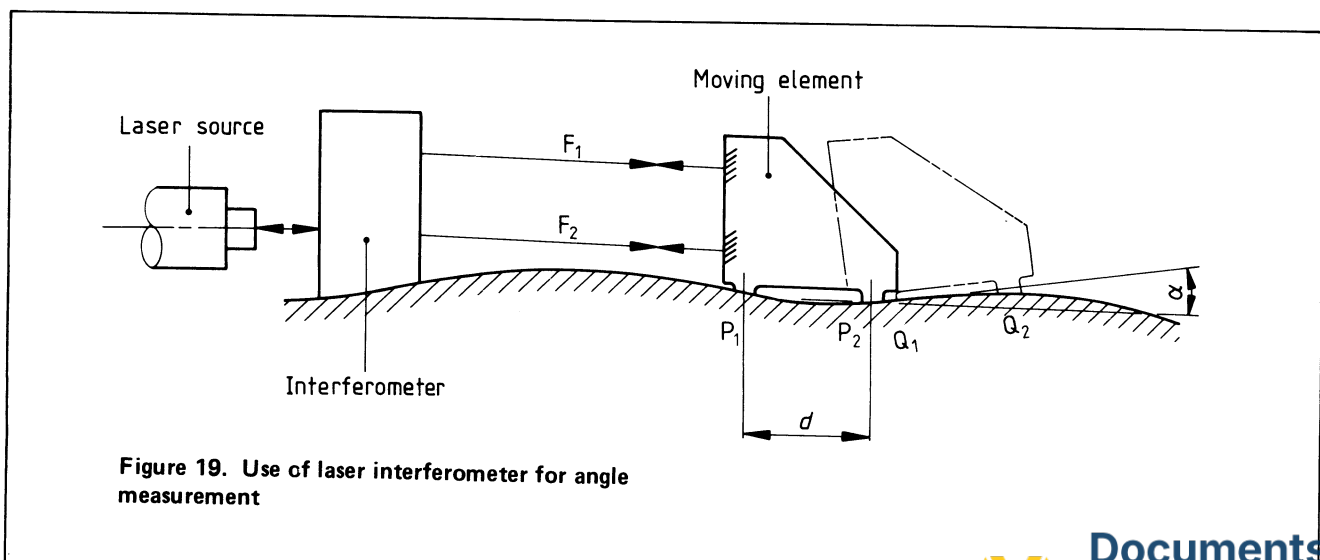
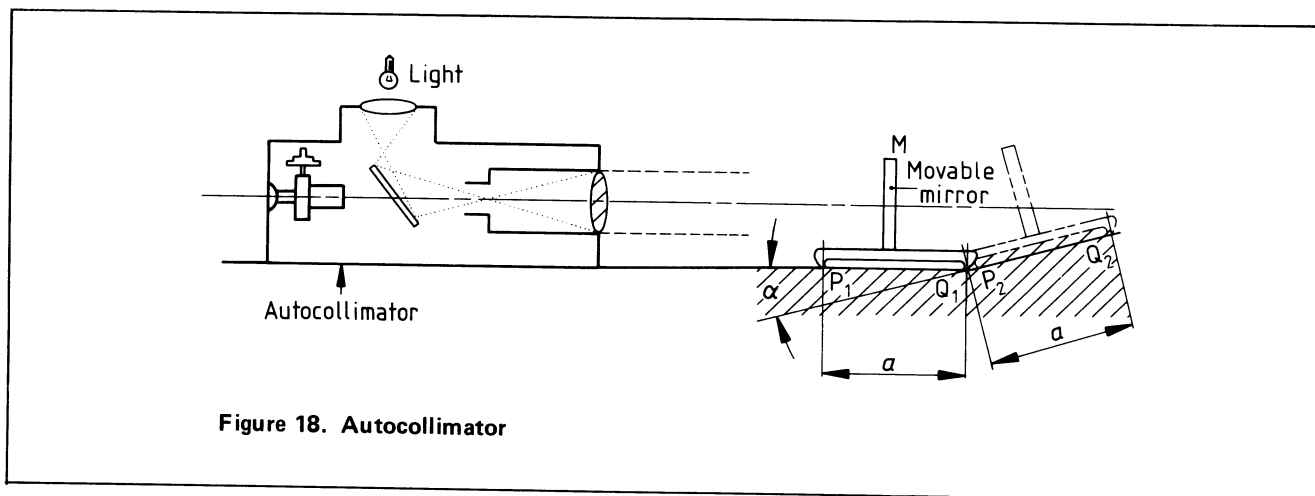
NOTE 2. The level permits checking the straightness only in the vertical plane; for the checking of a line in a second plane, another method should be used, e.g. taut-wire and microscope.

5.212.22 Autocollimation method. In this method, using an autocollimator mounted coaxially (see figure 18) any rotation of the moveable 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 α of the mirror holder to be determined. The measuring reference is composed of the optical axis of the telescope defined by the centre of the reticle.

NOTE 1. By rotating the ocular micrometer through 90° , rotation angle of moveable mirror M around a vertical axis can also be measured.

NOTE 2. In this method, the autocollimator has to be mounted on the element on which the line is to be checked.

5.212.23 Method by laser interferometry (angle measurement) (see figure 19 and A.9).



In this process the interferometer has to be rigidly fixed to the same element on which the line is to be checked.

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

5.213 Tolerance

5.213.1 The tolerance T is limited by two straight lines separated by distance t and parallel to the reference line AB (see figure 20 (a)). The maximum deviation indicated is MN.

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

5.213.2 A minimum tolerance T_1 is specified for any measuring length L smaller than or equal to L_1 (see figure 20(a)).

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

For any intermediate measuring length (between L_1 and L_2) (see figure 20(b)) the tolerance is calculated by a proportional method, as follows:

$$\text{where } L \leq L_1, \quad T(L) = T_1;$$

$$\text{where } L_1 < L < L_2 \quad T(L) = T_1 + \frac{T_2 - T_1}{L_2 - L_1} (L - L_1);$$

$$\text{where } L \geq L_2, \quad T(L) = T_2.$$

5.22 Straightness of elements.

5.221 Definition. The conditions for the straightness of an element are the same as those for a line (see 5.211).

5.222 Methods of measurement

5.222.0 General. 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 should read deviations in the normal plane of the line through the points P or Q with h kept to a minimum (see figure 21(a)).

In the case of angular deviation measurements the distance d determines the measuring point spacing (see figure 21(b)).

The moving element shall lie flat on the table, preferably resting 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 21(b)).

Straightness deviations of more complex reference surfaces (see figure 21(c)) are measured in the functional planes of the slideway (lines HH_1 and VV_1) and not square to the reference plane.

5.222.2 Slideways

5.222.20 General. 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

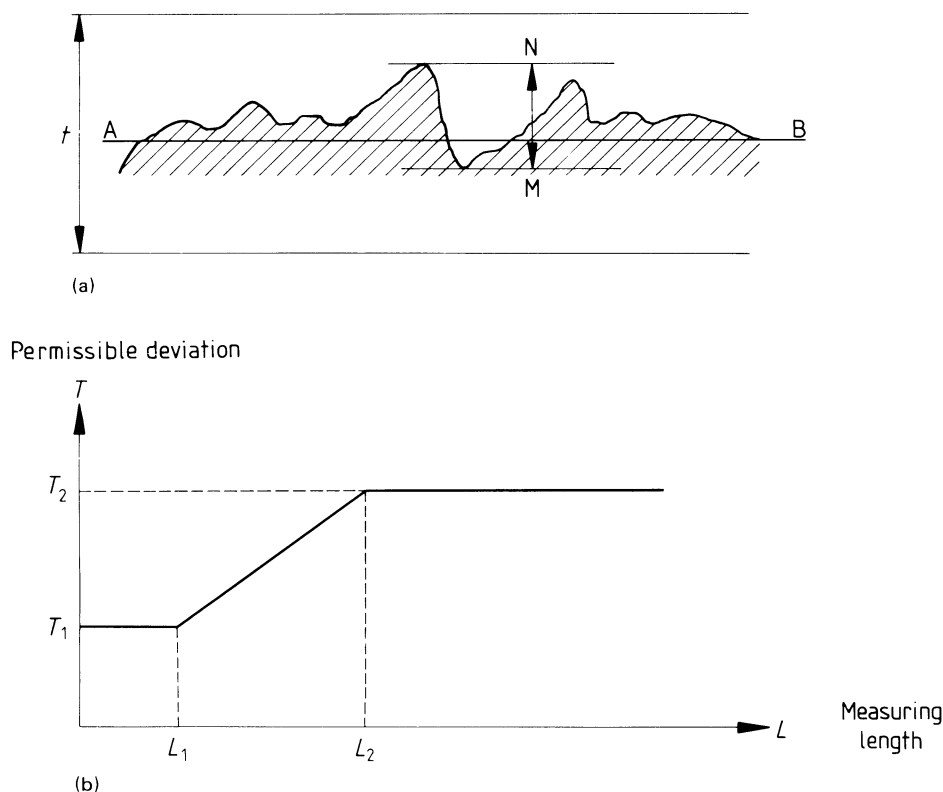
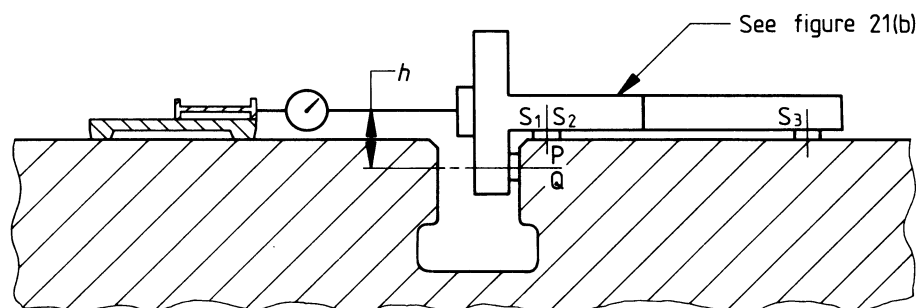
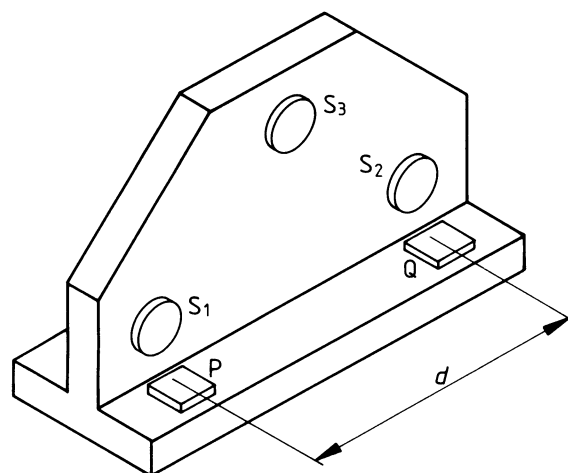


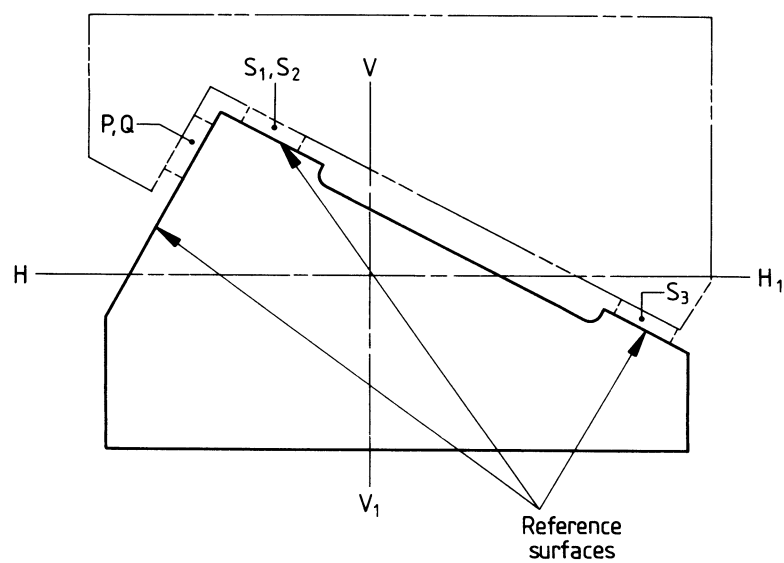
Figure 20. Tolerance zones



(a)



(b)



(c)

Figure 21. Measuring straightness

should only be carried out if the component is accessible. More complex slideways have to be checked as part of the measurement of the straight line motion of the moving element (see 5.23).

The deviation of straightness should always be checked in the functional plane. Generally, this can be regarded as either 'horizontal' (line AA in figure 22(b)) or 'vertical' (line BB in figure 22(b)) although exceptions may occur with certain machine configurations (see figure 24).

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, either:

- (a) one plane or several small sections jointed together; or
- (b) several narrow plane sections, cylindrical slideways or an assembly of the two.

5.222.21 Vee surfaces. The moving body should bear on the surfaces at four contact points. It should also be

supported by an additional point on a different surface of the slideway for stability.

Figures 22(a) and 22(c) show the use of a recessed cylinder, and figure 22(b), an inverted recessed vee.

NOTE. The additional supporting point should on no account produce a positioning force on the moving component.

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 23(a) and 23(b)).

The same precaution should be taken as in 5.222.21 regarding the additional support of the block.

5.222.23 Single vertical surfaces. The moving body makes contact by two points P and Q on the surface to be measured and 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 23(c) and 23(d)).

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

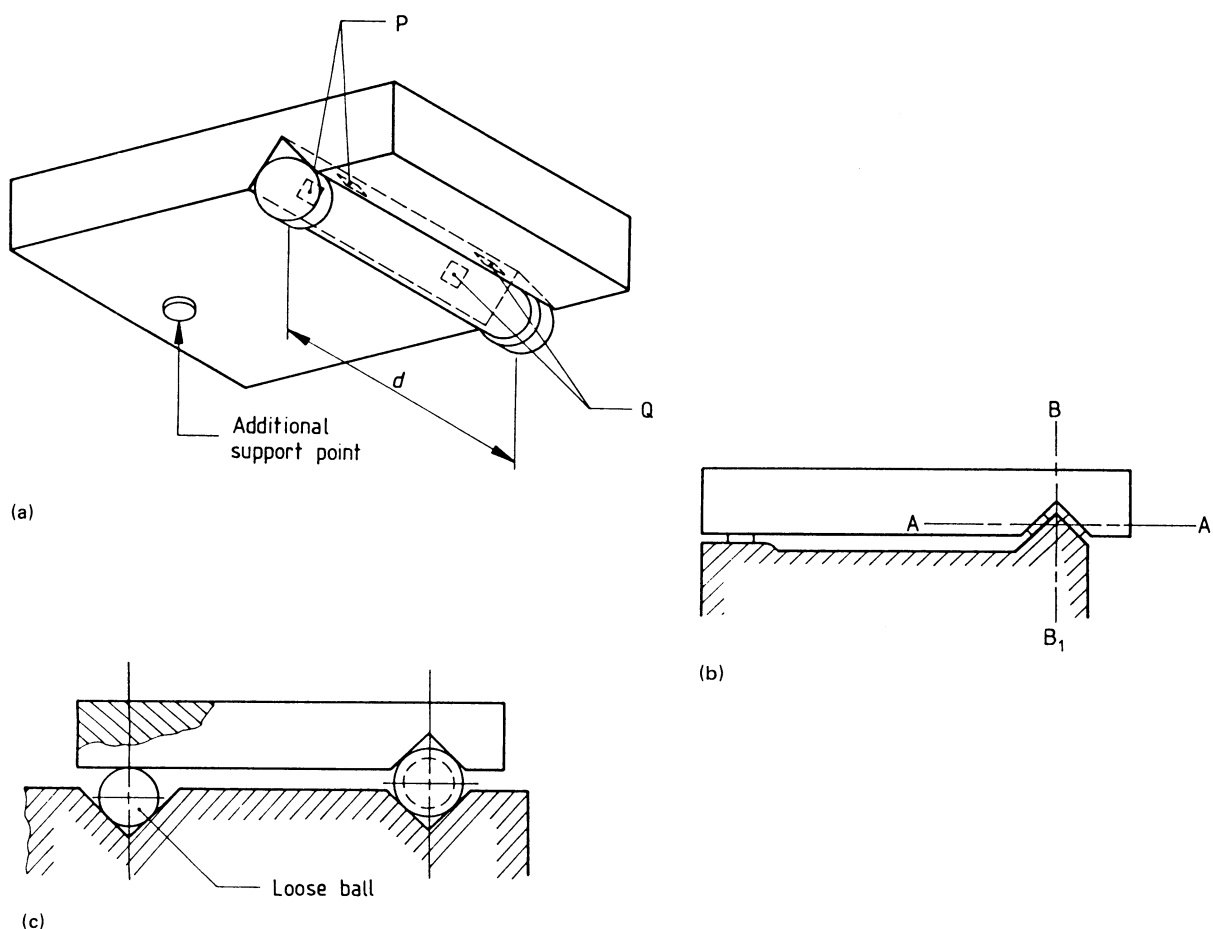


Figure 22. Supporting devices for vee surfaces

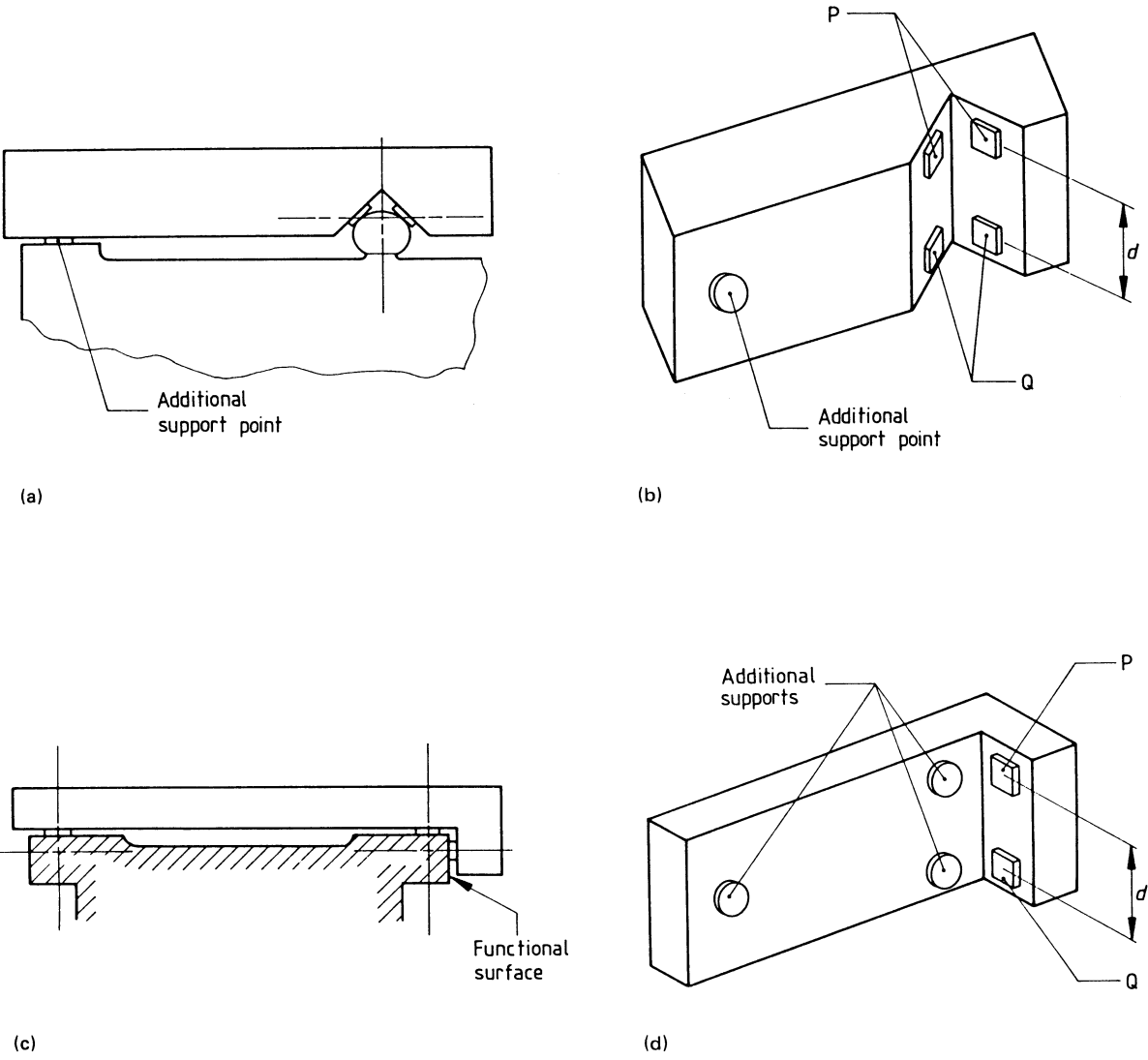


Figure 23. Supporting devices for vertical surfaces

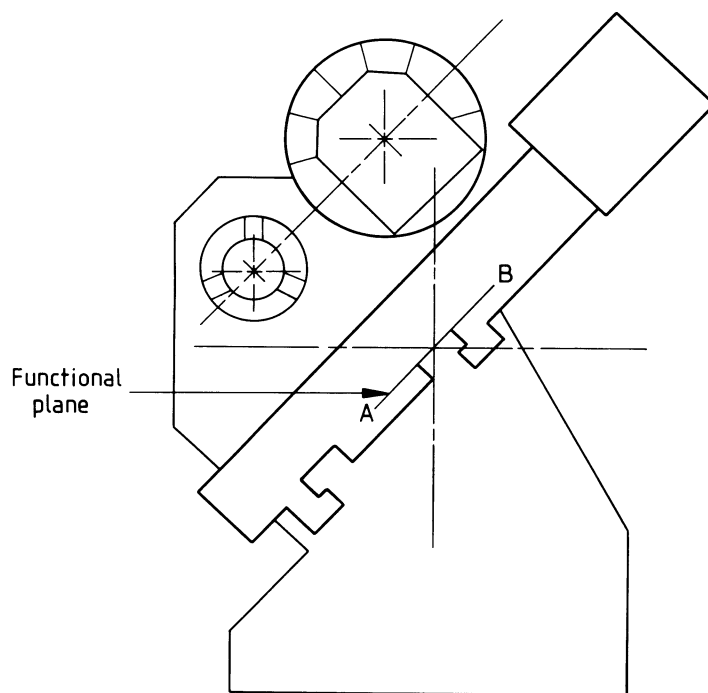


Figure 24. Slant bed configuration

5.222.24 Slant-bed configuration (see figure 24). 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.

5.223 Tolerances. See 5.213.

5.23 Straight-line motion

5.230 General. Testing for straight-line motion of each element of a machine tool ensures that the machine will produce a straight or flat workpiece.

5.231 Definitions

5.231.0 General. The straight-line motion of a moving element always involves linear and angular deviations. When a moving element carries the cutting tool, usually only linear deviations at the tool position influence the results, but when the moving element carries the workpiece, both linear and angular deviations can influence the results.

5.231.1 linear deviations. Linear deviation of straight-line motion is determined by the straightness of the trajectory of the functional point or the representative point of a moving element.

NOTE. The functional point is the position of the tool when a moving element carries the tool and, when a moving element carries the workpiece. The centre of table may be regarded as the representative point.

5.231.2 angular deviation. Angular deviations apply to an element whenever it is moved. These angular deviations are called rolling, pitching and yawing as shown in figure 25.

All linear and angular 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 on the moving element is different from the representative point and a separate measurement has to be made. The value of each angular deviation is the maximum angle turned through during a complete traverse of the moving element.

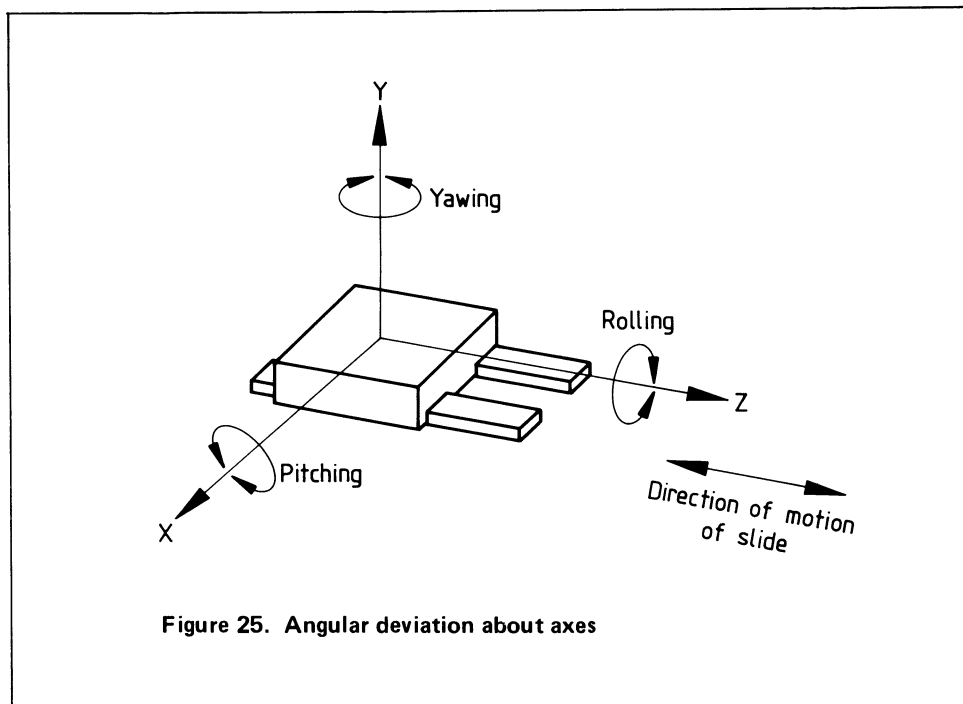


Figure 25. Angular deviation about axes

5.232 Methods of measurement

5.232.0 General. For checking the trajectory of the representative point, including angular deviation, and/or motion of an element, the following methods are used:

- (a) measurement using straightedge and dial gauge (see 5.232.1);
- (b) measurement using taut-wire and microscope (see 5.232.2);
- (c) measurement using alignment telescope (see 5.232.3);
- (d) measurement using a laser (direct measurement of straight lines) (see 5.232.4).

For straight-line motion of an element past a representative point, including angular deviation, one of the following methods should additionally be used:

- (1) measurement using precision levels (see 5.232.5);
- (2) measurement using auto-collimators (see 5.232.6);
- (3) measurement using lasers (see 5.232.7).

NOTE 1. Not all methods will check all deviations.

NOTE 2. In the case of a length greater than 1600 mm, see 5.212 regarding the choice of the method of measurement.

5.232.1 Method of measurement using a straightedge and dial gauge. When using a straightedge and dial gauge it is usual to fix the straightedge to the element 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.5).

5.232.2 Method of straightness measurement using taut-wire and microscope. This method is comparable to the straightedge and dial gauge method where the taut wire represents the straightedge and the microscope represents the dial gauge (see A.11).

5.232.3 Method of straightness measurement using alignment telescope. 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.13).

5.232.4 Method of straightness measurement using a laser. When using a laser (direct measurement using a straightness interferometer), the elements defining the measuring reference have to be firmly fixed to the component chosen as reference. The measuring reference is fixed to the tool holder and its centre is situated as near as possible to the active zone of the tool.

NOTE. This method is not recommended for lengths over 5 m (see A.9).

5.232.5 Method of angular deviation measurement using a precision level (see 5.212.2). When using a precision level the instrument is fixed to the moving element. The element is moved incrementally and the level readings recorded after each move.

5.232.6 Method of angular deviation measurement using an autocollimator (see 5.212.22). When using an autocollimator the mirror is mounted on the moving element and the autocollimator on the reference line.

5.232.7 Method of angular deviation measurement using a laser (see 5.212.23). When using a laser the remote interferometer and beam bender should be fixed on the reference line and the laser reflector mounted on the moving element.

5.233 Tolerance

5.233.1 Tolerance for the linear deviation of straight-line motion. The tolerance determines the permissible deviation of the straight-line motion of a representative point relating to the reference line (general direction of the trajectory) and dimensions.