

BRITISH STANDARD 3800 : 1964

Confirmed March 1979

UDC 621.9—187

**METHODS FOR
TESTING
THE ACCURACY OF
MACHINE TOOLS**

BRITISH STANDARDS INSTITUTION

METHODS FOR TESTING THE ACCURACY OF MACHINE TOOLS

B.S. 3800 : 1964

Confirmed March 1979

Incorporating amendment issued April 1974 (AMD 1386)

BRITISH STANDARDS INSTITUTION

Incorporated by Royal Charter

2 PARK STREET, LONDON, W1A 2BS

Telex: 266933

Telephone: 01-629 9000

THIS BRITISH STANDARD, having been approved by the Mechanical Engineering Industry Standards Committee and endorsed by the Chairman of the Engineering Divisional Council, was published under the authority of the General Council on 19th October, 1964.

The Institution desires to call attention to the fact that this British Standard does not purport to include all the necessary provisions of a contract.

In order to keep abreast of progress in the industries concerned, British Standards are subject to periodical review. Suggestions for improvements will be recorded and in due course brought to the notice of the committees charged with the revision of the standards to which they refer.

A complete list of British Standards, numbering over 9000, fully indexed and with a note of the contents of each, will be found in the BSI Catalogue. The BSI Catalogue may be consulted in many public libraries and similar institutions.

This standard makes reference to the following British Standards:

- B.S. 308. Engineering drawing practice.
- B.S. 817. Cast iron surface plates and granite surface plates for inspection and marking purposes.
- B.S. 818. Cast iron straightedges (bow shaped and I-section).
- B.S. 907. Dial gauges for linear measurement (excluding lever type).
- B.S. 939. Engineers' squares including cylindrical and block squares.
- B.S. 958. Precision levels for engineering workshops.
- B.S. 1660. Machine tapers.
- B.S. 1916. Limits and fits for engineering.
- B.S. 2795. Dial test indicators (lever type) for linear measurement.

British Standards are revised, when necessary, by the issue either of amendment slips or of revised editions. It is important that users of British Standards should ascertain that they are in possession of the latest amendments or editions.

The following B.S.I. references relate to the work on this standard:

Committee reference MEE/6/24

Draft for comment D63/5447

CONTENTS

	Page		Page
Co-operating organizations	3	5.3. Flatness	13
Foreword	4	5.4. Parallelism, equidistance and coincidence	14
		5.5. Squareness	19
		5.6. Rotation	23
METHODS OF TEST			
INTRODUCTION			
1.1. Scope	4	SPECIAL CHECKS	
1.2. Definitions	4	6.1. Division	28
GENERAL CONSIDERATIONS		6.2. Determination of the rectilinear deviations of screw-driven components	30
2.1. Definitions relating to geometrical checks	4	6.3. Angular play	30
2.2. Testing methods and use of checking instruments	4	6.4. Trueness of devices with angular indexing (e.g. turrets)	30
2.3. Tolerances	5	6.5. Intersection of axes	30
PRELIMINARY CHECKING OPERATIONS		APPENDIX A	
3.1. Installation of the machine before testing	7	CHECKING INSTRUMENTS	
3.2. Condition of the machine before testing	7	1. General	32
PRACTICAL TESTS		2. Straightedges	32
4.1. Testing	8	3. Squares	32
4.2. Checking of workpieces in practical tests	8	4. Precision levels	32
4.3. Importance of practical tests	8	5. Dial gauges	32
GEOMETRICAL CHECKS		6. Surface plates	32
5.1. General	8	7. Test mandrels	32
5.2. Straightness	8		

CO-OPERATING ORGANIZATIONS

The Mechanical Engineering Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

- | | |
|--|---|
| Associated Offices' Technical Committee | Institute of Petroleum |
| Association of Consulting Engineers | Institution of Civil Engineers |
| Association of Mining Electrical and Mechanical Engineers | Institution of Gas Engineers |
| British Chemical Plant Manufacturers' Association | Institution of Heating and Ventilating Engineers |
| British Compressed Air Society | *Institution of Mechanical Engineers |
| *British Electrical and Allied Manufacturers' Association | Institution of Mechanical Engineers (Automobile Division) |
| British Gear Manufacturers' Association | *Institution of Production Engineers |
| British Internal Combustion Engine Manufacturers' Association | Locomotive and Allied Manufacturers' Association of Great Britain |
| British Iron and Steel Federation | London Transport Board |
| British Mechanical Engineering Federation | *Machine Tool Trades Association |
| *British Railways Board | *Ministry of Defence, Army Department |
| Crown Agents for Oversea Governments and Administrations | *Ministry of Defence, Navy Department |
| *D.S.I.R.—National Engineering Laboratory | Ministry of Labour (H.M. Factory Inspectorate) |
| Electricity Council, the Generating Board and the Area Boards in England and Wales | Ministry of Power |
| Engineering Equipment Users' Association | *Ministry of Public Building and Works |
| Gas Council | Ministry of Transport |
| High Commission of India | National Coal Board |
| Institute of Marine Engineers | National Physical Laboratory (D.S.I.R.) |
| | Radio Industry Council |
| | Royal Institute of British Architects |

The Government departments and scientific and industrial organizations marked with an asterisk in the above list, together with the following were directly represented on the Committee entrusted with the preparation of this standard:

- | | |
|---|--|
| Association of Supervisory Staffs, Executives and Technicians | North East Coast Institution of Engineers and Shipbuilders |
| Machine Tool Industry Research Association | Production Engineering Research Association |
| Ministry of Aviation | Society of Motor Manufacturers and Traders Ltd. |
| Ministry of Defence, Air Force Department | Trades Union Congress |
| National Federation of Engineers' Tool Manufacturers | |

BRITISH STANDARD METHODS FOR TESTING THE ACCURACY OF MACHINE TOOLS

FOREWORD

For a number of years the United Kingdom has been an active and prominent participant in the work of Technical Committee 39—Machine Tools—of the International Organization for Standardization (ISO), and among a number of important projects on which international agreement has been achieved is the Recommendation R 230—'Machine Tool Test Code'.

In view of the importance attached to this recommendation by both the manufacturers and users of machine tools, it has been agreed that its requirements should be implemented in this British Standard, the object of which is to establish the terms, definitions and methods for testing the accuracy of machine tools by means of geometrical and practical tests.

*As amended
April 1974*

Metal working and woodworking machine tools are defined in B.S. 4640, 'Classification of metal working machine tools by types' and B.S. 3997, 'Classification of woodworking machines and auxiliary equipment' respectively.

Geometrical and, in many cases, practical tests for particular types of machine tool are dealt with in B.S. 4656, 'Specification for the accuracy of machine tools and methods of test' which is published in a number of parts.

This standard gives essentially a recommended selection of testing methods by means of geometrical checks. Attention is drawn to the fact that, while geometrical checks are explained at length, the practical tests are not, as the problems of the inspection of elements regarding position, dimensions and forms are fully dealt with in most technical books of metrology.

It relates only to the checking of the accuracy itself and does not cover the checking of the running of the machine tool (vibrations, abnormal noises, slip and stick motion of elements), nor with the checking of characteristics (speeds, feeds), as such checks should normally be carried out before checking the accuracy of the machine tool.

METHODS OF TEST

1. INTRODUCTION

1.1 Scope. This British Standard describes 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. An appendix deals with the accuracy of instruments used for testing machine tools.

1.2 Definitions.

Geometrical checks. The checking of dimensions, forms and positions of elements of the machine, and of their displacement relative to one another. They comprise all the operations which affect the elements of the machine (surface flatness, coincidence and inter-section 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.

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

2. GENERAL CONSIDERATIONS

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.

Metrological definitions are concrete, 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.

Nevertheless, 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.

2.2 Testing methods and use of checking instruments. During the testing of a machine tool, if the methods of measurement only allow verification that the tolerances

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

It should be emphasized that errors of measurement due to the instruments, as well as to the methods used, are to be taken into consideration during the tests. The measuring instrument should not give any error of measurement exceeding a known fraction of the tolerance to be verified. The accuracy of the devices used being very variable 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 (sunlight, electric lamps too close, etc.) and the temperature of the measuring instruments should be stabilized before measuring. The machine itself should be suitably protected from the effects of external heat.

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

2.3 Tolerances.

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

There are also tolerances which apply only to test pieces.

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

- the unit of measurement used,
- the reference base and the value of the tolerance and its location in relation to the reference base
- 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: degree, minute, second or as tangents (microns or millimetres per metre for countries using the metric system or inch per 10 in or inch per foot for countries using the inch-foot system).

When the tolerance is known for a given range, the tolerance for another range comparable to the first one 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:

Tolerance of run-out: $X\mu$

Inaccuracy of instruments, errors of measurement: $Y\mu$

Maximum permissible difference in the readings during the test: $(X - Y)\mu$

Errors of block gauges, reference discs, etc., 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 neglected.

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

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

2.32 Subdivisions of tolerances.

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

2.321.1 Tolerances of dimensions. The tolerances of dimensions indicated in this 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 compliance with the rules given in B.S. 308, 'Engineering drawing practice'. The methods of indicating the tolerance by stating the maximum material condition and the deviation or by giving the basic size and the limits in the symbols of B.S. 1916, 'Limits and fits for engineering', are preferred.

Example: 1.500
 $+ .0016$ or $1.5 H 8$

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 plunger surface or of the support surface, part only of the error of form is detected. Therefore where extreme accuracy is required, the area of the surface covered by the plunger or support should be stated.

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

NOTE. It should be noted that rules for indicating geometrical tolerances on drawings are given in B.S. 308 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 a component relative to a line, to a plane, or to another component of the machine (e.g. deviation of parallelism, of perpendicularity, of alignment, etc.). They are expressed in units of length or angle.

If 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. It should be noted that rules for indicating geometrical tolerances on drawings are given in B.S. 308 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 Fig. 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. (If thought useful, preliminary checks may ascertain defects of form of lines and of surfaces, of which the relative positions are to be determined.)

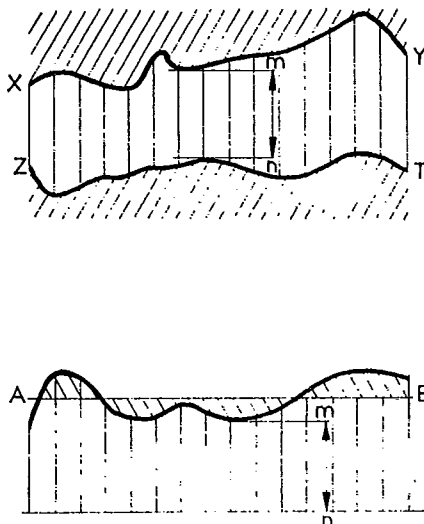


Fig. 1

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

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

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

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

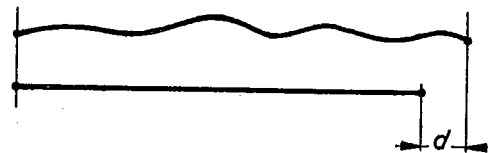


Fig. 2

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

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

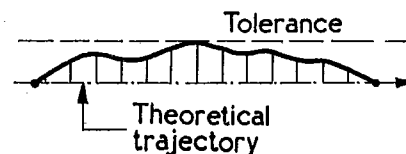


Fig. 3

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

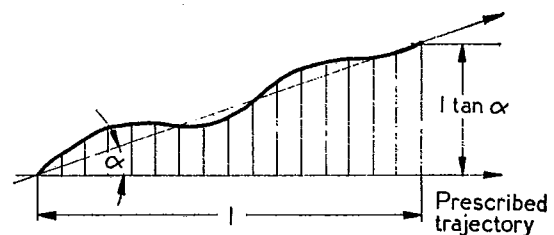


Fig. 4

2.322.4 Local tolerances. Tolerances of form or position are usually relative to the form or position as a whole, e.g. 0.03 per 1000 for a straightness or flatness. It should be observed that checking can show up a deviation (see Fig. 5) which is not spread over the whole of the form or position, but is concentrated on a short length of the former (e.g. 200 mm). If such defects, seldom met with in practice, are to be avoided, the overall tolerance may be accompanied by a statement of a local tolerance; or it may be simply agreed that the local tolerance, provided that it does not fall below a minimum to be stated (e.g. 0.01 or 0.005 mm) should be proportional to the overall tolerance. In the case under consideration, relating e.g. to straightness, the local error should not in these conditions exceed:

$$\frac{0.03}{1000} \times 200 = 0.006 \text{ mm}$$

If 0.01 mm is accepted as a minimum for any given machine, it is sufficient to check that the local error does not exceed this value.

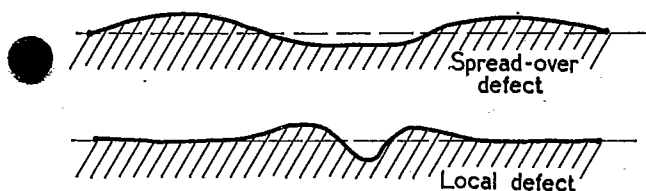


Fig. 5

In practice, local defects are generally imperceptible, as they are covered by the supporting or the feeling surfaces of the measuring instruments. However, when the feeling surfaces are relatively small (plungers of dial gauges or micro-indicators), the measuring device should be such that the plungers follow a surface of high grade finish (straightedge, test mandrel, etc.). (See measuring device, Fig. 8.)

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

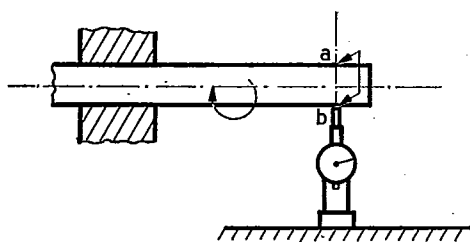


Fig. 6

2.324 Symbols and positions of tolerances for relative angular positions of axes, slideways, etc. When the position of the tolerance in relation to the nominal position is symmetrical, the sign $\pm$ may be used. If the position is asymmetrical it should be stated precisely, in words, either in relation to the machine or to one of the components of the machine, or in relation to the operator in his conventional position.

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

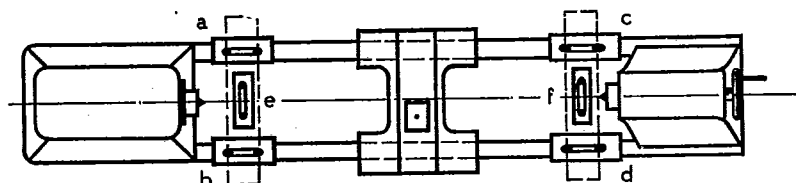


Fig. 7

3. PRELIMINARY CHECKING OPERATIONS

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

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

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

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

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

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

3.2 Condition of the machine before 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 grinding machine table in order to check the slideways).

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

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

4. PRACTICAL TESTS

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

The number of workpieces or, as the case may be, the number of cuts to be made on a given workpiece, 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.

4.2 Checking of workpieces in practical tests. Checking of workpieces in practical tests should 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 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. There are cases moreover when, on account of expense or technical difficulties in conducting the tests, the accuracy of a machine is checked only by geometrical checks or only by practical tests.

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

5. GEOMETRICAL CHECKS

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

Straightness	see 5.2
Flatness	see 5.3
Parallelism, equidistance and coincidence	see 5.4
Squareness	see 5.5
Rotation	see 5.6

a definition*, a method of measurement and the way of determining the tolerance are given.

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

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

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

* See also 2.1.

5.2 Straightness. Geometrical checks covering straightness are the following:

Straightness of a line in two planes	see 5.21
Straightness of components	see 5.22
Straight line motion	see 5.23

5.21 Straightness of a line in two planes.

5.211 Definition.

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

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

5.212 Methods of measurement. It is recommended that for lengths below 1600 mm or 63 in a spirit level or straight-edge be used, and that for lengths above 1600 mm or 63 in measurement should be by means of a spirit level, or optical devices (the auto-collimation method, the microscope and taut wire).

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

The measurement 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 plunger of which is in contact with the straightedge (see Fig. 8).

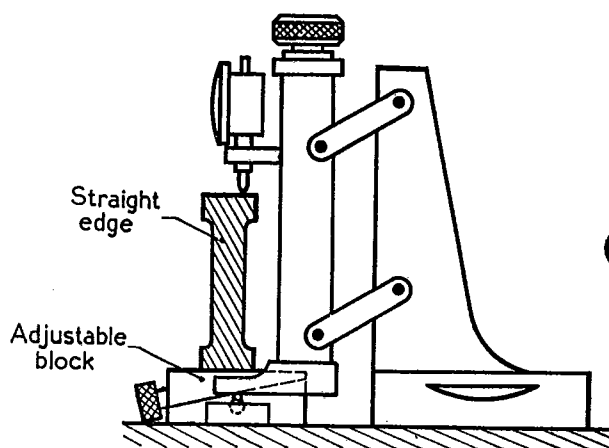


Fig. 8

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

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

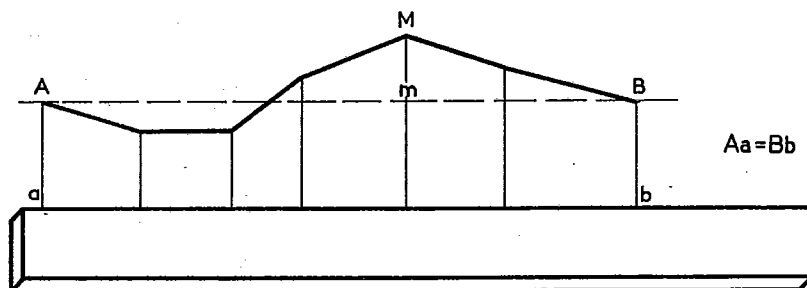


Fig. 9a

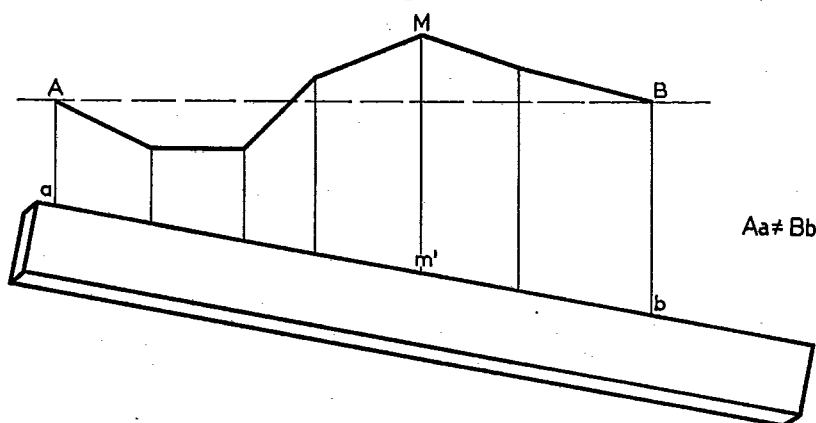


Fig. 9b

5.212.2 Spirit-level method or autocollimation method.

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

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

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

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

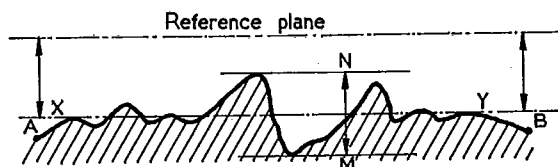


Fig. 10

5.212.21 Spirit-level method.

a. When the line is reasonably horizontal. The initial straight line of reference is constituted by the straight line omX , o and m being two points on the line to be checked (see Fig. 11).

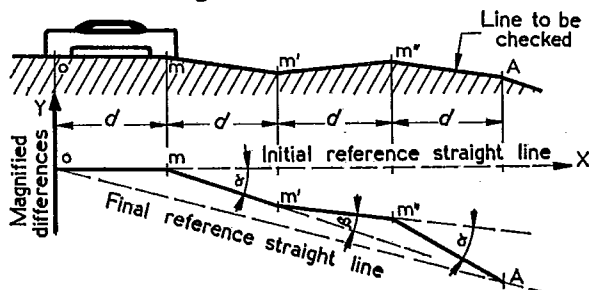


Fig. 11

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

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

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

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

b. When the line is not horizontal. When a line is inclined, the procedure of the last example may be applied, if a support having an angle α equal to the angle of inclination in relation to the horizontal plane is used (see Fig. 12).

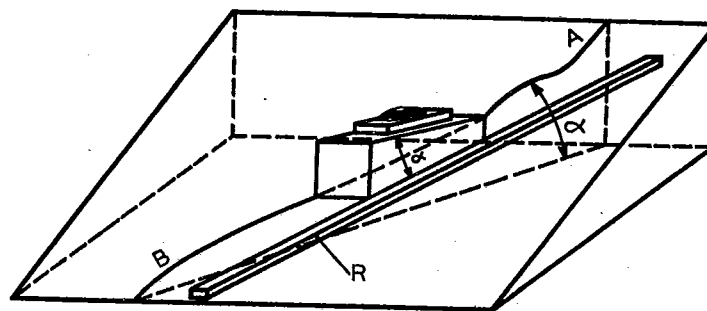


Fig. 12

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

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

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

b. In the method using an accurate alignment telescope (see Fig. 14), 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.

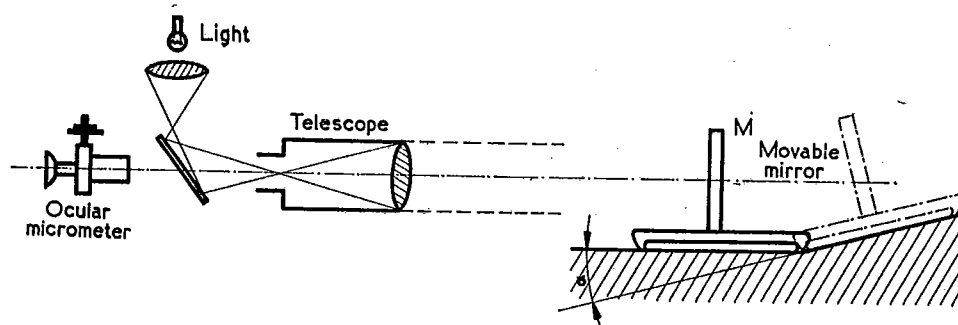


Fig. 13

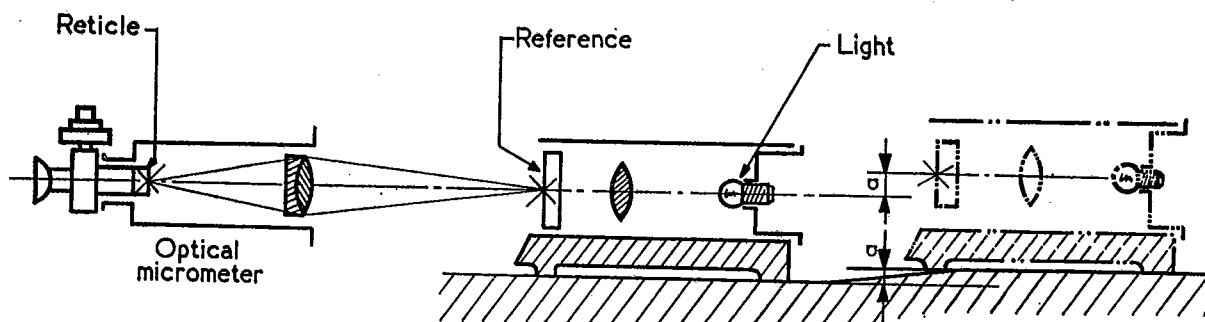


Fig. 14

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

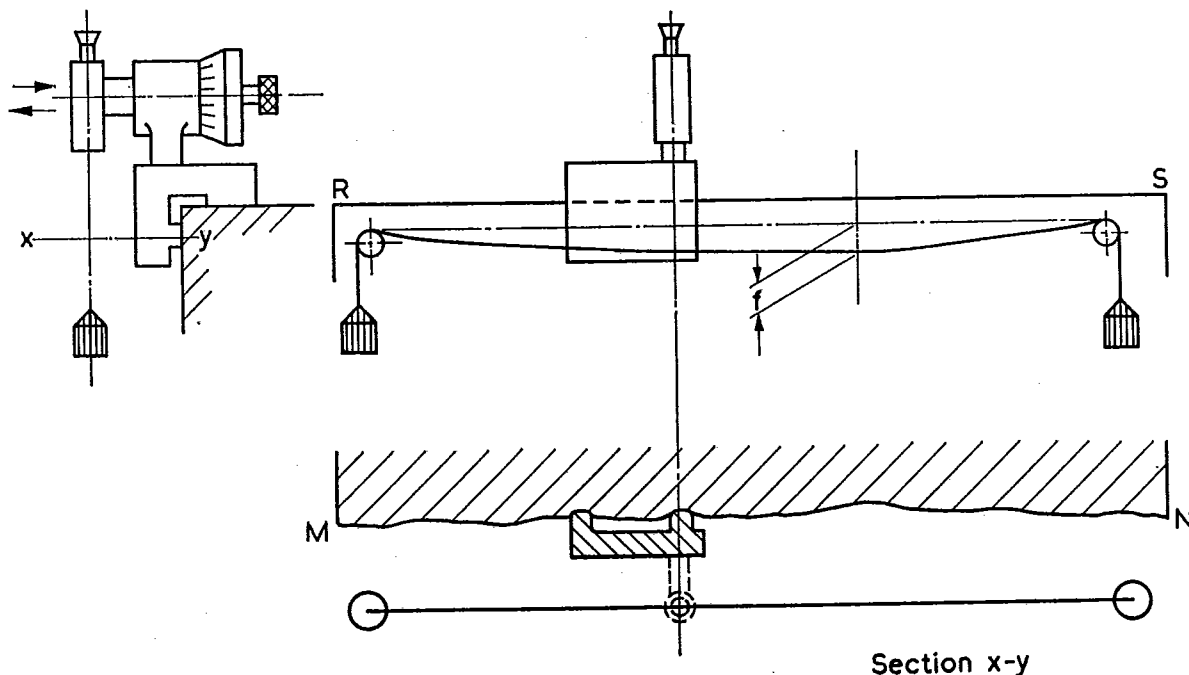


Fig. 15

5.212.3 Checking by means of the taut wire and microscope. A steel wire (or nylon cord), having a diameter of about 0.004 in (0.1 mm) is stretched in order to be approximately parallel to the line to be checked (see Fig. 15). For example, in the case of a line *MN*, located in a horizontal plane, with a microscope placed vertically and equipped with a horizontal micrometric displacement device, it is possible to read the deviation of the line to the taut wire in the horizontal plane of measurement *xy*.

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

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

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

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

5.22 Straightness of components.

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

This clause relates particularly to slideways of machine tools.

5.222 Methods of measurement. The methods indicated in 5.212.1 to 5.212.3 are applicable for plane slideways.

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

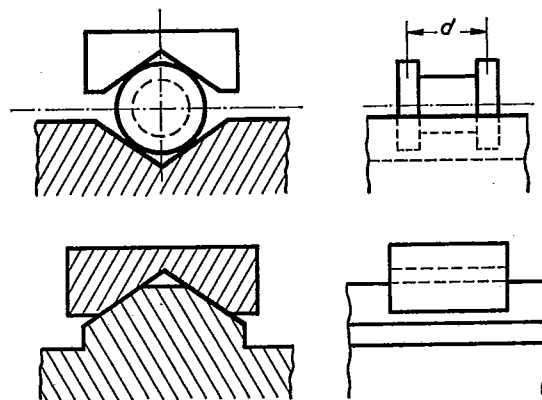


Fig. 16

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

- Checking of the slideways lengthwise, either with the level for straightness in a vertical plane (support faces *A* and *B*), or the taut wire (3) and microscope (1) for straightness in a horizontal plane,
- Checking of the slideways crosswise with the level (support faces *B* and *C*).

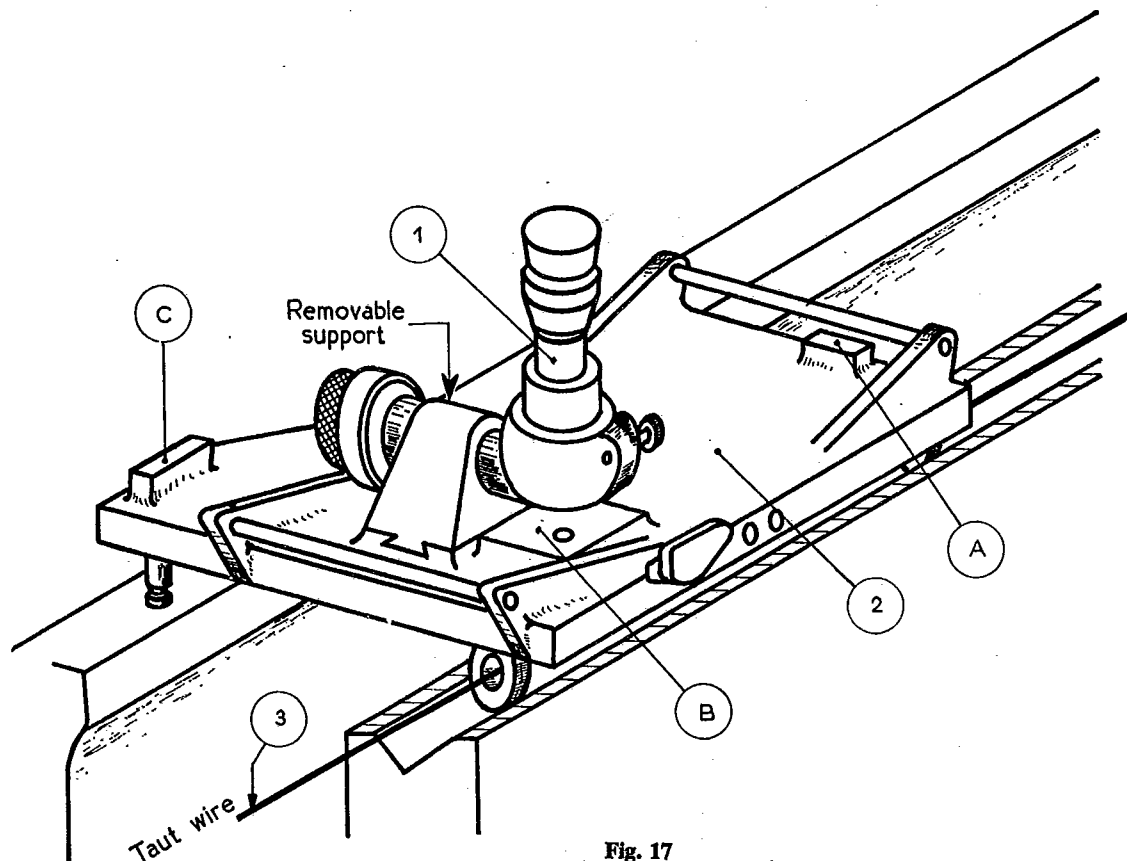


Fig. 17

5.223 Tolerances. The tolerances are the same as those defined in 5.213.

5.23 Straight line motion.

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

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

There are several kinds of straight line motion, namely:

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

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

5.232.1 Checking with a straightedge and a dial gauge. A dial gauge should be fixed to the moving element of the machine, the stylus sliding along the straightedge representing the reference line (see Fig. 18).

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

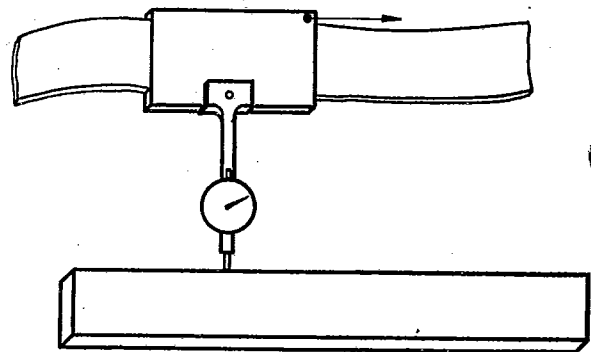


Fig. 18

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

5.232.3 Checking the straightness of a lathe slide displacement. (This checking is in fact effected only in the horizontal plane.)

a. *Displacements not exceeding 1600 mm (63 in).* A test mandrel mounted between centres should be used.

A dial gauge is mounted on the saddle in the place of the tool and the stylus brought into contact with the