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1989

Incorporating Amendment No. 1

Coordinate measuring machines —

Part 3: Code of practice

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Committees responsible for this British Standard

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Advanced Manufacturing Technology Research Institute
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Department of Trade and Industry (National Engineering Laboratory)
Department of Trade and Industry (National Physical Laboratory)
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Contents

Foreword

This Part of BS 6808 has been prepared by the Advanced Manufacturing Technology Assembly (AMT/-/8) at the request of manufacturers and users of coordinate measuring machines (CMMs).

BS 6808-2:1987, which covered the performance assessment of coordinate measuring machines, has been superseded by BS EN ISO 10360-2:1996. Amendment No. 1 to BS 6808-3:1989 deletes all reference to BS 6808-2:1987, which has been withdrawn.

This Part of BS 6808 provides the user and supplier with more information about further testing recommendations for variable environmental conditions.

A glossary of terms is given in BS 6808-1.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 14, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

This Part of BS 6808 gives recommendations to the user and supplier on the more detailed testing recommended if the environmental conditions give rise to problems.

This standard is not intended for coordinate measuring machines that have working volumes, any dimension of which is significantly greater than the dimension of the mechanical reference artefact, or for those having more than three non-redundant axes.

2 Definitions

For the purposes of this Part of BS 6808, the definitions given in BS 6808-1 apply.

3 General

The CMM under test should have validated software capable of determining from a series of data points the orientation in space of a best-fit plane. This ability will enable a much closer scrutiny of the measurement capability of the CMM to be made.

4 Environmental conditions

4.1 Vibration analysis

4.1.1 *Principle*. The vibration survey establishes the vertical and horizontal vibration environment at the interface between the CMM and its foundations and support system provided by the user, in order to allocate responsibility for faults between user and supplier.

4.1.2 *Procedure*. Make the vibration survey using a directionally sensitive, low frequency (0.5 Hz to 100 Hz) transducers capable of discriminating a peak-to-peak motion amplitude of 0.25 μm.

A band-pass filter of corresponding frequency range having variable high and low cut-off frequencies should be used to condition the transducer signals prior to recording on an oscilloscope, a chart recorder or in some other way agreed between the user and the supplier.

In the case of a contacting analogue probe, vibration between the mechanical probe and the workpiece can result from forces external to the CMM, or from forces generated within the CMM itself. Therefore, a test should first be made to see if the CMM is the vibration source, prior to conducting a full measurement and analysis of vibration. If the CMM is motorized, the power to all motors should be removed and the CMM tested to determine if the vibration is still present. If the CMM uses air bearings, the air pressure to the bearings should be varied sufficiently to establish whether air-bearing instability is causing vibration.

If the CMM is not the source of the vibration, a complete vibration analysis at the CMM-to-support interface should be performed and the frequency spectrum analysed to determine if frequencies and amplitudes are present that exceed the CMM supplier's defined limits. Measurements should be made by transducers mounted on the CMM support in the direction of the vertical axis and the two mutually perpendicular horizontal directions that approximately correspond to the principal axes of the CMM.

Care should be taken that the survey is undertaken during a period representative of the CMM operating conditions.

4.1.3 *Analysis*. If any of the vibration parameters measured during the survey (see **4.1.2**) exceed the supplier's specification, the user should correct the problem in order to conform to the specification or else accept a performance derating to be negotiated between supplier and user. If the vibration parameters are within the supplier's specification, it should be the sole responsibility of the supplier to correct the performance of the CMM in order to meet the specification.

4.2 Air supply

4.2.1 Procedures are described for testing the air supply if there is evidence of excessive pressure fluctuation, inadequate supply pressure at the specified flow rate, excessive CMM thermal drift, or bearing contamination. Responsibility for correction of faults is allocated between the user and supplier according to the analysis of the test results.

4.2.2 *Test equipment*. For the tests on the air supply, it is recommended that an air pressure gauge, air flow gauge, and a temperature measuring system should be used. The air pressure gauge should be calibrated to cover the range between the minimum and maximum air supply pressure specified by the CMM supplier.

The accuracy of the air pressure gauge should be ± 5 % of the permissible air supply pressure fluctuation as specified by the supplier.

The air flow gauge should have an accuracy of ± 20 % of the maximum flow rate specified by the supplier.

The temperature measuring system should be calibrated to an accuracy of ± 0.1 °C.

NOTE An accuracy of ± 0.1 °C is acceptable in most cases but would be dependent upon the specification of the CMM.

4.2.3 *Methods*

4.2.3.1 *Pressure fluctuation.* Mount an air pressure gauge in the supply line upstream of the CMM air filter. Observe the pressure under the condition(s) that resulted in evidence of excessive pressure fluctuation.

4.2.3.2 *Supply pressure and flow.* Using the gauge arrangement as described in **4.2.3.1**, observe the pressure under the condition(s) that resulted in evidence of inadequate pressure. If the pressure is inadequate, mount an air flow gauge in the supply line upstream of the CMM air filter. Observe flow under the condition(s) that resulted in evidence of inadequate pressure.

4.2.3.3 *Air supply temperature.* Mount a temperature measuring system pickup in the air line downstream of the CMM air filter or, if this is impractical, on a metallic part of the supply line as close to the inlet point on the CMM as possible. If the pickup is mounted on the line, the line and pickup should be insulated from ambient air to ensure that the temperature of the air supply is being measured. Measure the temperature under the condition(s) that resulted in evidence of excessive CMM thermal drift.

4.2.3.4 *Contamination.* Examine surfaces near air exhaust points for water, oil, or solid particulates, at a frequency dependent upon the frequency of use of the CMM but normally at least once per week.

4.2.4 *Test analysis*

4.2.4.1 *Pressure fluctuation.* If the supply line fluctuation exceeds the supplier's specification, it should be the responsibility of the user to correct the problem by, for example, installing an accumulator.

4.2.4.2 *Supply pressures and flow.* If the flow rate exceeds the supplier's specification, it should be the responsibility of the supplier to reduce the flow required by the CMM, provided it can be demonstrated by the user that no significant leaks exist in the supply. If the flow rate meets the supplier's specification but the line pressure does not, it should be the responsibility of the user to increase the supply pressure, for example by removing other devices using air from the line or by increasing its diameter.

4.2.4.3 *Air supply temperature.* If the temperature of the air supply line does not meet the supplier's specification, it should be the responsibility of the user to correct the temperature, for example by installing a heat exchanger to enable the supplier's specification to be met.

4.2.4.4 *Contamination.* If contamination is present, it should be the responsibility of the user to change the air filter cartridge, clean the CMM air system using procedures recommended by the supplier, and correct the supply contamination problem. Two methods of correction are preferred:

a) reduction of supply contamination; or

b) decrease of the intervals between servicing the filter.

NOTE External sources of dust, for example from air-conditioning and from ineffective cleaning procedures should be carefully controlled. Unexpectedly large variations in the values obtained from a series of measurements could arise from a contamination problem.

4.3 External temperature influences

Temporal and spatial temperature changes within the working volume of the CMM will affect the accuracy capabilities of the CMM and whenever possible such variations should be minimized. Among the influencing factors are heat radiation from: sunlight, neighbouring machines, lighting and, where applicable, the proximity of the operator.

The deviation of the CMM and/or the workpiece from a reference temperature will also produce measurement errors even when the temperature remains constant with time, unless the effective thermal coefficient of expansion and the temperature of the CMM are the same as the expansion coefficient and temperature of the workpiece. It is recommended that the CMM and workpiece should be fitted with temperature sensors.

The effects of temperature should be corrected by calculation based upon the known thermal parameters of the CMM and workpiece. It is recommended that such computations are based on the assumptions that the temperature is steady with time and is uniform in space.

Careless handling of mechanical reference artefacts can cause significant errors. For example, if a 400 mm length bar is grasped with unprotected hands for about 10 s, its length could be in error by more than 15 µm even after 15 min.

4.4 Other machine influences

4.4.1 *Workpiece*. Unless the CMM is specially designed and constructed to completely decouple the static and dynamic yield behaviour of the CMM from its measurement system, this will usually lead to the deformation of the guides and hence, measuring errors. To be able to keep such deviations within acceptable limits, it is recommended that the supplier specifies maximum values for the permissible deadweight of a workpiece and, where applicable, limiting values for the distribution of loads applied to the measuring volume of the CMM.

The properties of the workpiece to be tested do have an influence on the measured coordinate values obtained. Surface quality, shape, hardness, elastic and, where applicable, plastic yield to gravity and the probing force, have effects on the measured values. Workpieces may in some circumstances become deformed by the applied probing forces because of their shape and/or the material from which they are made. It is possible in many cases to correct for this effect. When measuring soft workpieces, for example, wax models and plastics, the probe sphere may become impressed in the workpiece due to the probing force and thus lead to error.

4.4.2 *Definition of the measuring task*. Poor definition of the measuring task on a technical drawing or in the test procedure should also be regarded as a potential source of error. With incorrect or ambivalent indication of dimensions or reference points, or the selection of unsuitable reference elements or the incorrect choice of definition for the fitting procedure, undesired deviations will occur in the determination of the result of a measurement.

5 Choice of mechanical reference artefacts

5.1 Performance verification and periodic reverification

5.1.1 *General*. The choice of a mechanical reference artefact with which to undertake the verification and periodic reverification of CMM performance should be carefully considered. Several of the criteria are subjective and some may be offset, to some extent, by the availability of a suitable artefact at the time of the test. Ideally, the initial verification and the periodic reverification should be performed using the same artefact, or failing that, an artefact of the same general type. In **5.1.2** to **5.1.4** some of the aspects that the user should consider are discussed for the types of artefact that possess the following essential features required for verification of CMM performance:

a) mechanical perfection of the length-defining features;

b) certified accuracy;

c) dimensional stability;

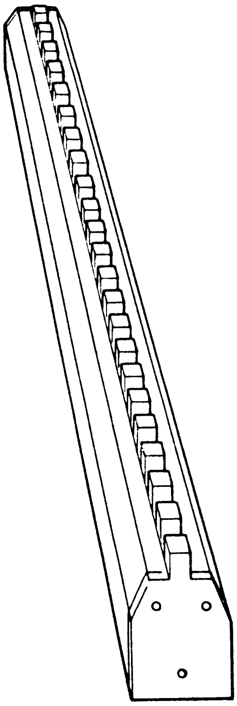
d) mechanical rigidity.

5.1.2 *Accuracy*. Whilst end bars have the potential to be calibrated to the highest accuracy, for routine applications there is little to choose between end bars and gauge blocks because both can be calibrated to ± 0.5 µm for a 1 000 mm gauge and 0.3 µm for a 500 mm gauge. The accuracy with which a step gauge can be calibrated is ± 0.8 µm to ± 1 µm for a 1 000 mm gauge.

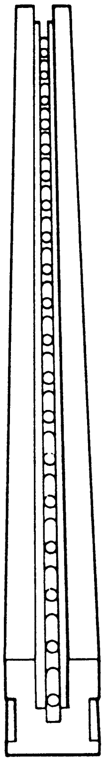
5.1.3 *Mechanical properties*. Gauges of monolithic construction, i.e. gauge blocks, end bars and certain types of step gauge, should have better dimensional stability than composite construction step gauges.

The mechanical rigidity is a difficult parameter to quantify because of the possible variations in the orientation of the artefact. Whilst most step gauges are designed to be used with two supports, some artefacts, for example gauge blocks, need a supplementary support system. Optimum support points are usually indicated by the suppliers and usually refer to points of least deflection when the gauge is inclined at specific angles, usually 0° and 45°. In order to minimize the effects of bending on the calibrated length, step gauges are usually designed with the measuring line at or near to the neutral axis of the gauge.

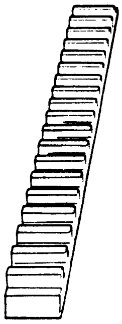
In Figure 1 to Figure 4, a number of recommended configurations for step gauges and gauge blocks are shown.



(a) Step gauge with castellations



(b) Step gauge with cylindrical inserts



(c) Step gauge with monolithic construction

Figure 1 — Step gauges

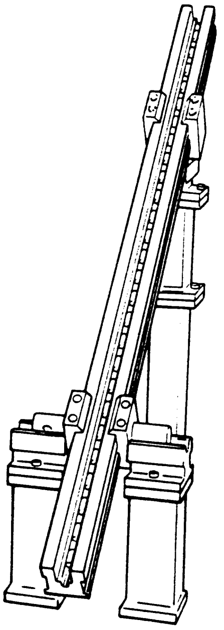


Figure 2 — Typical support arrangement for minimum deflection at 45° inclination

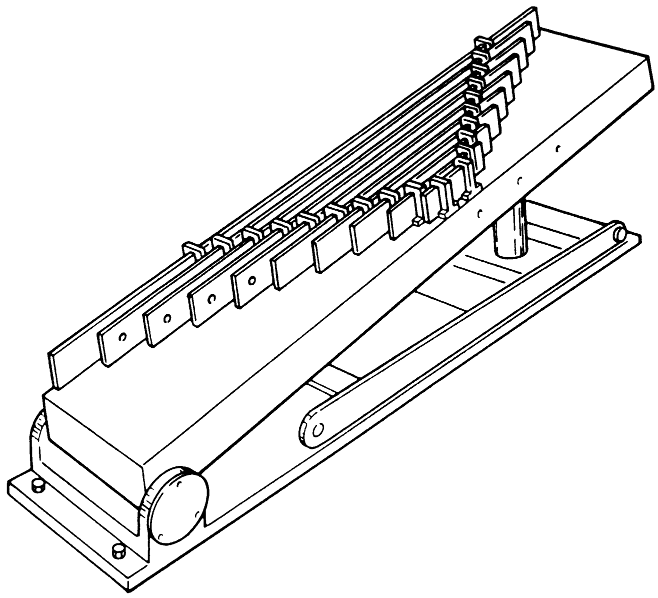


Figure 3 — Support for gauge blocks up to 1 000 mm arranged with measuring lines symmetrically disposed about a common centre

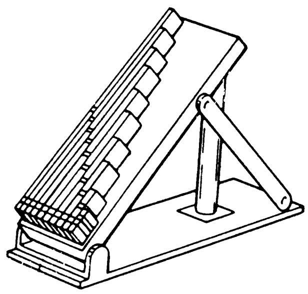


Figure 4 — Adjustable gauge block support system with a common end plane

5.1.4 *Operational considerations*. One disadvantage of using a series of gauge blocks or end bars is the necessity to align each gauge individually. Moreover each block creates only one test length so that such an arrangement is costly both in terms of purchasing the necessary (at least five) blocks and the time taken to perform the measurements. A step gauge, on the other hand, defines substantially more test lengths (sometimes up to 50) along a common measuring line, so it can be aligned and measured more quickly.

For the performance assessment of high-accuracy CMMs, thermal effects should be carefully considered. The large thermal mass of the step gauge tends to reduce temperature variations of the reference artefact, which is generally advantageous.

5.2 Artefacts for day-to-day performance checking

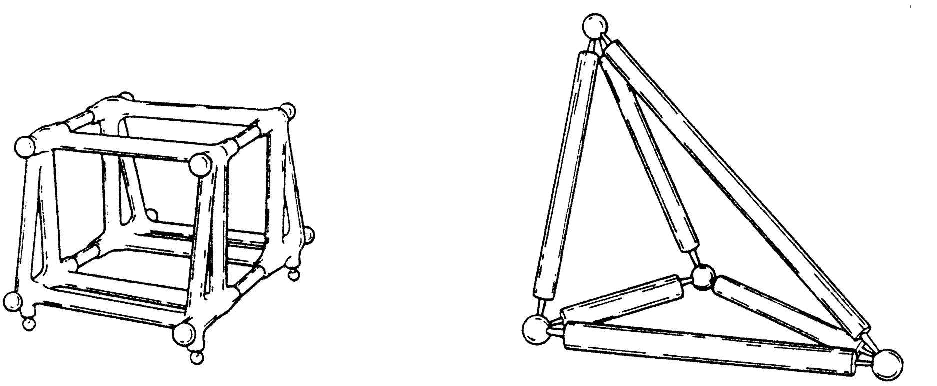
5.2.1 *General*. Suppliers and users of CMMs have devised and developed a wide range of artefacts to create a number of well-defined features the measurement of whose spatial coordinates can be used to check day-to-day performance. Several different types are available commercially, but frequently a user will use an “in-house” artefact for various reasons, for example the specific material may be important or the combination of test features critical.

5.2.2 *Rigid space frames.* Space frames of one sort or another have been popular as aids to performance checking since the earliest development of the CMM. In order to create a rigid framework encompassing a relatively large volume and yet maintain mechanical rigidity, the weight of the frame should be recognized as a key factor. Relatively heavy frames should be regarded as acceptable especially if hoists, etc. are readily available. Cast-iron or granite is often used as the basis of large solid artefacts. Again, the user should balance the conflicting characteristics of mechanical rigidity and long-term dimension stability with their considerable weight, which could easily distort the measuring CMM unless the user exercises considerable care.

Lightweight frames are perfectly satisfactory when the requirements for stability are somewhat less stringent. Space frames have been successfully manufactured from carbon-fibre composites with good dimensional stability.

NOTE Information on the use of space frames is given in Report EUR 10100 EN, 1985[1].

It is recommended that the user considers the applicability of the special purpose space frames and calibration artefacts shown in Figure 5 to Figure 7 for day-to-day performance checking.



(a) Eight ball space frame

(b) Four ball space frame

Figure 5 — Space frames

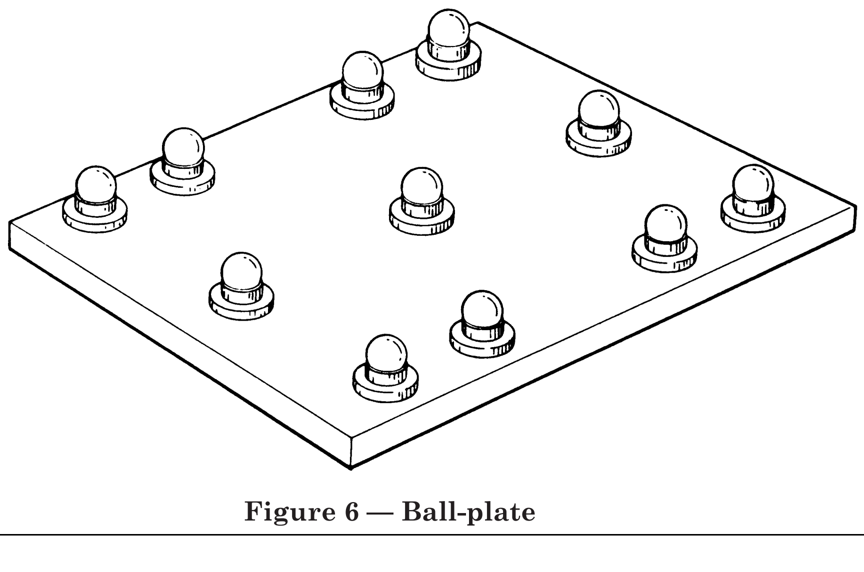


Figure 6 — Ball-plate

[1] Obtainable from the Commission of the European Communitie, Batiment Jean Monnet, Luxembourg.

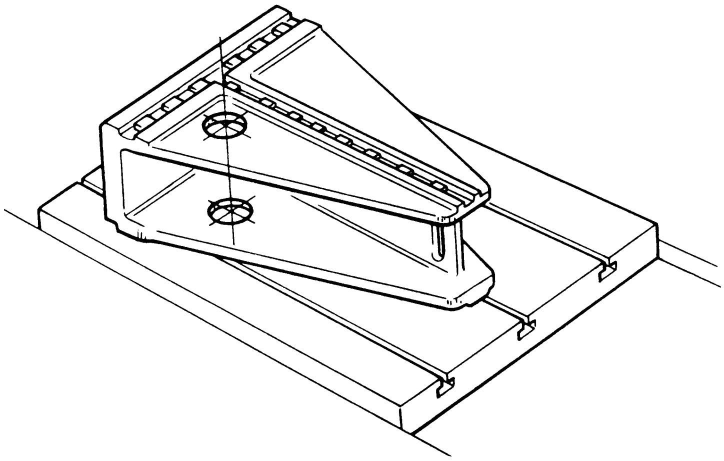


Figure 7 — A multi-purpose commercially-available artefact

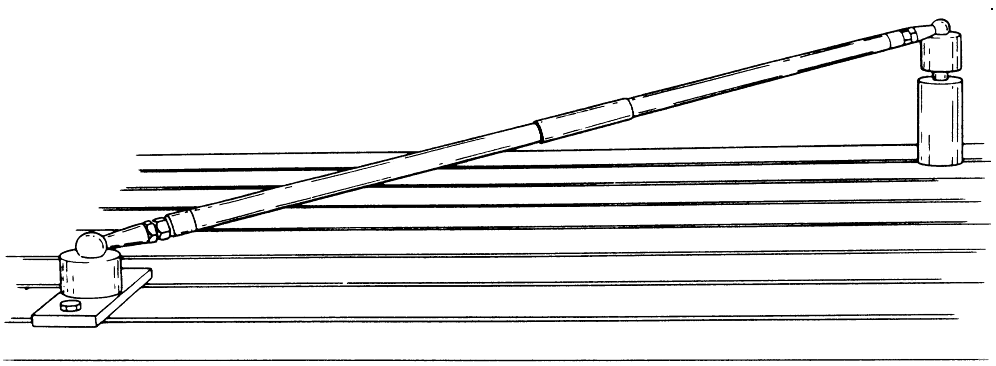


Figure 8 — Example of a ball-ended rod with magnetic cups for kinematic location

5.2.3 ***Synthetic space frames***

5.2.3.1 *General*. The user should consider the use of a synthetic space frame as an alternative technique for creating a number of well defined spatial features for day-to-day CMM checking.

5.2.3.2 *Ball-ended bars*. The user should consider the use of the ball-ended bar as a simple method of assessing CMM performance over a substantial fraction of the working volume of the CMM (see Figure 8).

NOTE More details of the artefacts and their use are contained in Standard ANSI ASME B89.1.12M.

The main problems arising from using such devices are:

a) the need to refer to spatial coordinates, e.g. the centre of the ball, which are not physically accessible to the probe;

b) the need to probe the test ball several times to determine the spatial coordinates from which the Euclidean distance between the centres of the test and the fixed ball can be calculated; and

c) the operational difficulty associated with most CMMs being unable to follow a circular path precisely.

The user should consider the possible use of an extendable bar system (see Figure 9); the complexity of processing the transducer signal may, however, reduce the attraction of this solution.

5.2.3.3 *Machine checking gauge*. A commercially-available device has been developed to overcome many of the problems normally associated with the use of ball-ended bars. It is recommended that the user consider the relative merits of this gauge (see Figure 10).

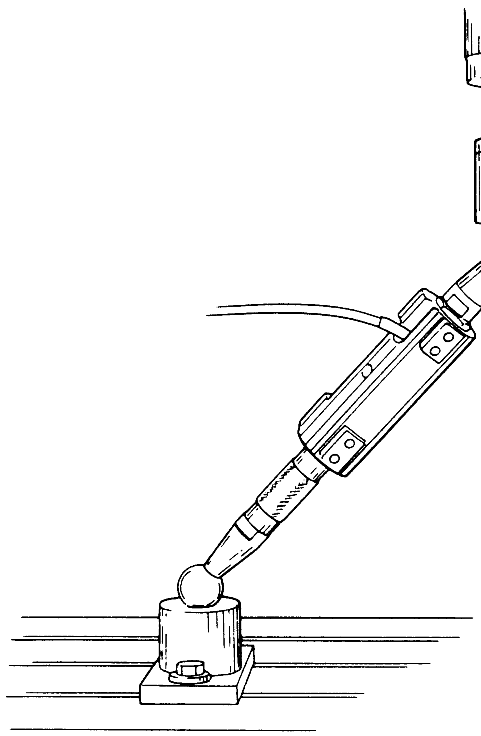


Figure 9 — Extendable bar system (see **5.2.3.2)**

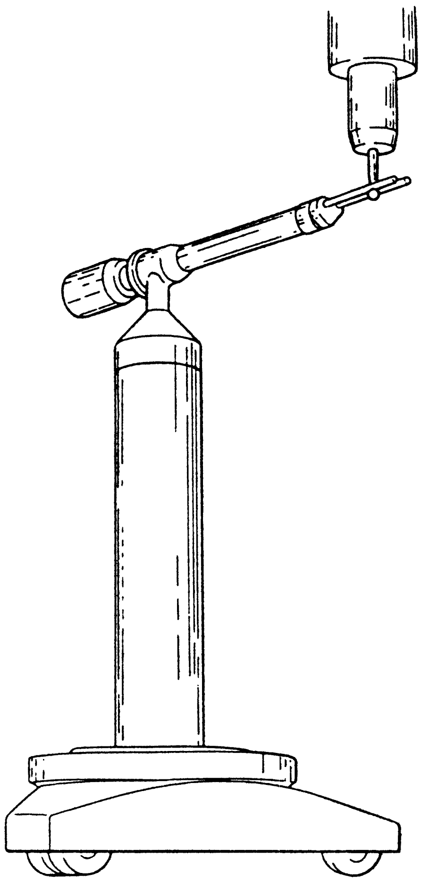


Figure 10 — Machine checking gauge

6 Performance verification tests

6.1 General

There are two factors which should be taken into account when carrying out the performance verification tests:

a) the arrangement of the measuring lines within the working volume of the CMM; and

b) the alignment of the measuring line to the calibrated length defined by the gauge.

No completely general method can be recommended for aligning gauge blocks and step gauges, and the user should choose the method which best suit the requirements of the job. However, some guidelines are set out in **6.3**.

6.2 Arrangement of the measuring lines

6.2.1 *General*. The user should be satisfied that there is complete freedom to choose the precise locations of the measuring positions within the working volume of the CMM.

Recommended methods for the assessment of the CMM are given in **6.2.2** to **6.2.4**.

6.2.2 *Cross-diagonals*. It is strongly recommended that the four cross-diagonals are checked irrespective of the particular types of measurements undertaken with the CMM. The working volume of the CMM is fully covered and it is unlikely that any squareness errors, which can be reduced by adjustment on many CMMs, would escape detection (see Figure 11).

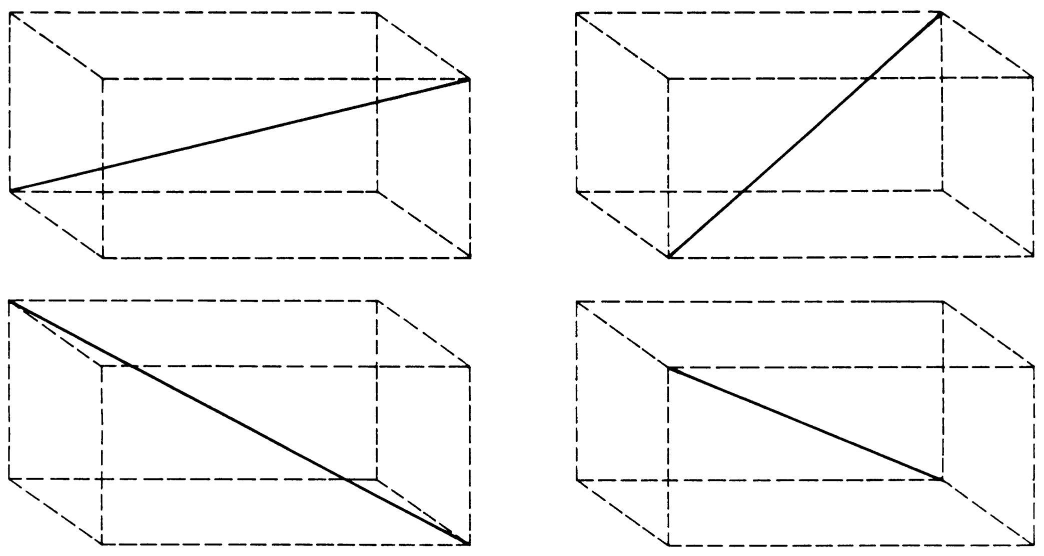


Figure 11 — The four cross-diagonal configurations

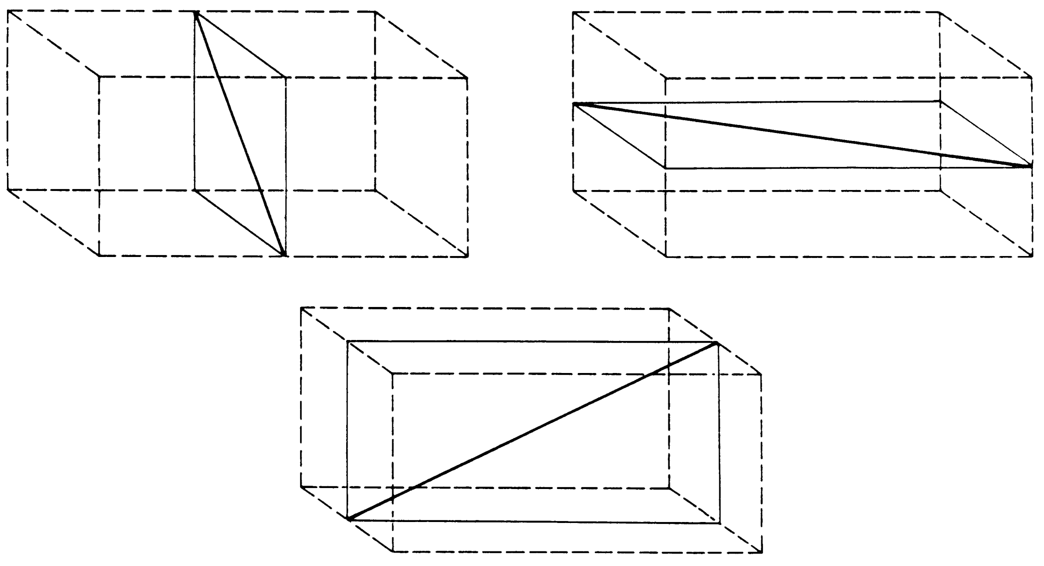


Figure 12 — In-plane diagonal configuration

6.2.3 *In-plane diagonals*. It is recommended that measuring lines along the diagonals of planes defined by pairs of principal axes are chosen (see Figure 12). Note that the CMM axis not in the plane under test should be operated at half the maximum extent of its travel.

6.2.4 *Additional measuring line*. As most measurements are performed at a height of about one third of the maximum travel of the vertical axis above the table of the CMM, there may be some advantage in investigating this region more closely (see Figure 13).

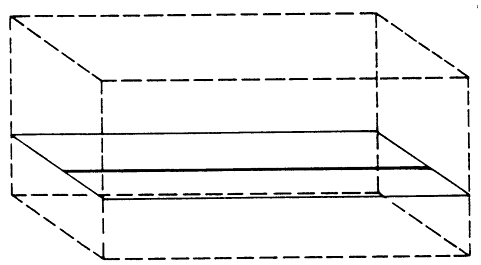
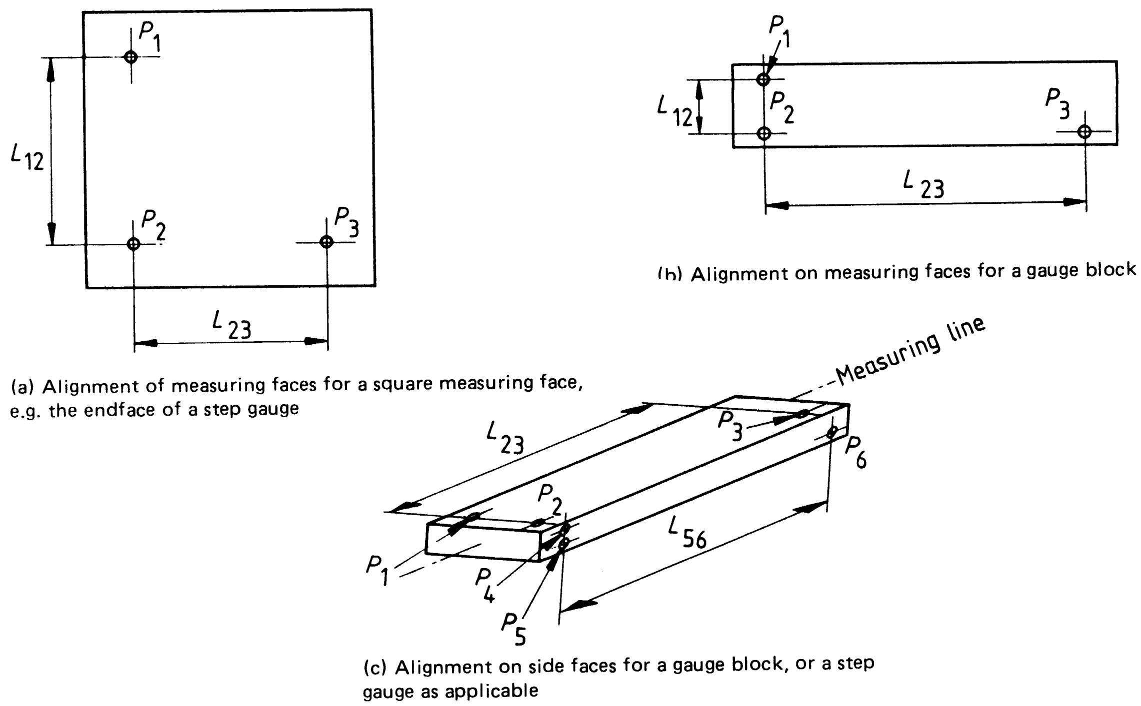


Figure 13 — Suggested additional measuring line



NOTE L_{ij} is the distance between sensing points P_i and P_j.

Figure 14 — Position of measuring points for mathematically determining alignment of test devices

6.3 Alignment of the measuring lines to the gauge

6.3.1 *General.* Estimating the uncertainty contributed by the misalignment of the gauge depends upon the alignment procedure. Two methods are recommended (see **6.3.2** and **6.3.3**).

6.3.2 *Aligning on the measuring faces.* A measuring face of a gauge block or step gauge, or the alignment end face of a step gauge, should be sensed at three points. The positions of the points should be chosen as in Figure 14 (a) or Figure 14 (b). The reference direction is determined by the perpendicular to the plane defined by these three points. The influence of incorrect alignment on the measured length of the gauge block, i.e. the cosine error E_K, in µm, can be estimated from the expression:

$$E_k \leq [(2A_3 + t_s)/L_{ij}]^2 L_r \quad (1)$$

where

- A_3 is the constant portion of length-measuring uncertainty (in µm);
- t_s is the tolerance for the range of error of the test device (in µm);
- L_r is the length of the gauge block (in µm);
- L_{ij} is the distance between sensing points P_i and P_j (in µm) (see Figure 14).

NOTE 1 In Figure 14 L_{ij} is L_{12}, L_{23} or L_{56}.

NOTE 2 Using expression 1, with A_3 = 1 µm, $L_r = 1 \times 10^6$ µm, t_s = 0.25 µm and $L_{12} = 6 \times 10^3$ µm, the cosine error $E_K \leqslant$ 0.14 µm.

NOTE 3 A_3 is a constant for the CMM which should be supplied by the CMM manufacturer.

6.3.3 *Aligning on the side faces*. For higher values of the constant portion of the length-measuring uncertainty A_3, it is recommended to align the measuring lines on the side faces. For this purpose for example three points on each of two sides of the (step) gauge are sensed. The distance between sensing points is chosen to be as large as possible (see Figure 14). A plane is defined by each set of three points. The line of intersection of both planes forms the reference direction. With T as the tolerance for squareness of the (step) gauge and L_{ij} the distance between measuring points [see Figure 14 (c)], the following expression represents the cosine error E_K, in µm.

$$E_K \leqslant [(2A_3 + T)/L_{ij}]^2 L_r \quad (2)$$

where

- A_3 is the constant portion of length-measuring uncertainty (in µm);
- T is the tolerance for squareness of the (step) gauge (in µm);
- L_r is the length of the gauge block (in µm);
- L_{ij} is the distance between sensing points P_i and P_j. (in µm).

NOTE 1 In Figure 14 (c) L_{ij} is L_{23} or L_{56}.

NOTE 2 Using expression 2, with A_3 = 10 µm, $L_r = 1 \times 10^5$ µm, $L_{23} = 9.5 \times 10^4$ µm and T = 100 µm, the cosine error is obtained as $E_K \leqslant$ 0.16 µm.

6.3.4 *Gauge blocks*. A gauge block should have the measuring lines aligned along its measuring faces. To do so, one face is sensed at a minimum of three points which should, as nearly as possible, form the vertices of a right-angled triangle and should be as far apart as is practicable [see Figure 14 (a)].

The plane passing through the spatial coordinates at the sensing points is determined mathematically by the software of the CMM and the perpendicular to this plane is deemed to be the reference direction.

After alignment, the gauge block is sensed once near the centre of each measuring face and the measured coordinates are projected on to the reference direction.

Key
1 Actual perpendicular to face
2 Calculated perpendicular to face
3 Projected sensing point
4 Gauge block

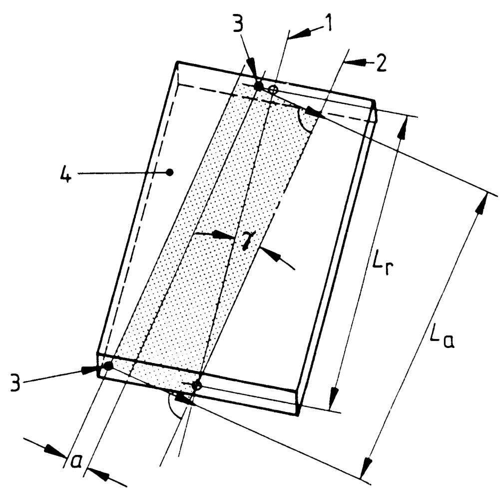


Figure 15 — Errors when aligning gauge blocks

The calculated distance between perpendicular points is the indicated value, L_a. The difference between L_a and the true length, L_r, of the gauge block contains both the instrumental error and the effect, E, of an alignment error. The relationship between E, L_a and L_r (taking all other errors in the instrument and gauge block as zero) is:

$$E = L_a - L_r$$
$$= 0.5\gamma^2 L_r + \gamma a \qquad (3)$$

where

L_a is the calculated length of the gauge block (in µm);

L_r is the true length of the gauge block (in µm);

a is the perpendicular distance of the projected sensing points from the calculated perpendicular to the surface (in µm);

γ is the angle between the calculated and actual perpendiculars (in radians).

The significance of a is shown in Figure 15, where the plane enclosed by the true and the calculated perpendiculars is shown shaded. If the sensing points are projected on to this plane, the projected sensing points are at a perpendicular distance from the calculated perpendicular to the surface.

The alignment error leads to a cosine error ($0.5\gamma L_r$) and a first-order error (γa), which is negligible for measurement under computer control, since in this case a can be chosen to be very small. With the instrument manually operated, i.e. with sensing points that are not numerically specified, the first-order term is of considerable importance. It is recommended to align the measuring lines on the measuring faces, particularly where the sensing system has only a very small uncertainty and where there is a high-resolution linear displacement measuring system. For low resolution, e.g. 10 µm, the alignment errors are considerable with long gauge blocks, e.g. 1 m, and in this case it is preferable to align the measuring lines on the side faces of the gauge block.

6.3.5 *Step gauges*. Step gauges generally are equipped with special alignment faces. Depending on the gauge design, the reference direction is the perpendicular to the front aligning face, or else is parallel to the line of intersection of two approximately perpendicular lateral aligning faces. Cases may arise where the aligning faces are not accessible in all positions of a step gauge. If so, the step gauge can be aligned on one measuring face. If this leads to an unacceptably large value for E, it is recommended that suitable side faces should be determined on the step gauge using a CMM, marked and then used for subsequent alignment. For practical purposes the particular aligning method is chosen which produces the least value of the cosine error, E_K. Careful reference should be made to the calibration certificate for the step gauge where the measuring line will be precisely specified.

7 Probing techniques

7.1 Probing for the performance verification

It should be the responsibility of the supplier to specify the type of probe used to achieve the accuracy value stated in the CMM specification sheets. It is likely, however, that the probing arrangements employed would be those that would lead to the most accurate measurements, i.e. a short stylus.

It is recommended that the supplier employs a configuration representative of normal usage of the CMM. The supplier should be encouraged to provide additional information about the performance with other probes.

7.2 Practical problems

The user should be aware that measurement errors are likely to increase as the probe tip is mounted further away from the line of the z-axis; this is because the z-axis of most CMMs roll, i.e. rotate about the z-axis. The greater the probe-offset the greater the error. However, other defects in the geometry of the CMM will generate measurement errors due to the probe tip being displaced, so great care should be exercised when using large probe offsets.

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Publications referred to

BS 6808, *Coordinate measuring machines.*
BS 6808-1, *Glossary of terms.*
BS EN ISO 10360-2, *Performance assessment of Coordinate Measuring Machines (CMMs).*
ANSI/ASME B89.1.12M, *Methods for performance evaluation of Coordinate Measuring Machines.*
Report EUR 10100 EN, *The intercomparison of three-dimensional measurements taken from CMMs.*

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