BRITISH STANDARD

BS ISO 230-6:2002

Test code for machine tools —

Part 6: Determination of positioning accuracy on body and face diagonals (Diagonal displacement tests)

ICS 25.080.01

British Standards

National foreword

This British Standard reproduces verbatim ISO 230-6:2002 and implements it as the UK national standard.

The UK participation in its preparation was entrusted to Technical Committee MTE/1, Machine tools, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

Cross-references

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Test code for machine tools —

Part 6: Determination of positioning accuracy on body and face diagonals (Diagonal displacement tests)

Code d'essai des machines-outils —

Partie 6: Détermination de la précision de positionnement sur les diagonales principales et de face (Essais de déplacement en diagonale)

Reference number
ISO 230-6:2002(E)

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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

Attention is drawn to the possibility that some of the elements of this part of ISO 230 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 230-6 was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

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

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

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

— *Part 3: Determination of thermal effects*

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

— *Part 5: Determination of the noise emission*

— *Part 6: Determination of positioning accuracy on body and face diagonals (Diagonal displacement tests)*

— *Part 7: Axes of rotation — Methods for specifying and testing*

Annex A of this part of ISO 230 is for information only.

Test code for machine tools —

Part 6:
Determination of positioning accuracy on body and face diagonals (Diagonal displacement tests)

1 Scope

This part of ISO 230 specifies diagonal displacement tests which allow estimation of the volumetric performance of a machine tool. Complete testing of the volumetric performance of a machine tool is a difficult and time-consuming process. Diagonal displacement tests reduce the time and cost associated with testing the volumetric performance.

A diagonal displacement test is not in itself a diagnostic test, although conclusions of a diagnostic nature may sometimes be possible from the results. In particular, when face diagonal tests are included, a direct measurement of the axes squareness is possible. Diagonal displacement tests on body diagonals may be supplemented by tests in the face diagonals, by tests parallel to the machine axes in accordance with ISO 230-2, or by the evaluation of the contouring performance in the three coordinate planes as defined in ISO 230-4.

Diagonal displacement tests may be used for acceptance purposes and as reassurance of machine performance where parameters of the test are used as comparison index.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 230. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 230 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 230-1:1996, *Test code for machine tools — Part 1: Geometric accuracy of machines operating under no-load or finishing conditions*

ISO 230-2:1997, *Test code for machine tools — Part 2: Determination of accuracy and repeatability of positioning numerically controlled axes*

ISO 230-3:2001, *Test code for machine tools — Part 3: Determination of thermal effects*

ISO 230-4:1996, *Test code for machine tools — Part 4: Circular tests for numerically controlled machine tools*

3 Terms and definitions

For the purposes of this part of ISO 230, the following terms and definitions apply.

3.1
working volume
volume defined by the travel of the machine linear axes for machining operations (not including those travels used for auxiliary operations, e.g. tool change)

3.2
body diagonal
D
space diagonal of a rectangular prism within the working volume of the machine tool

NOTE 1 Four body diagonals are defined by the working volume.

NOTE 2 The user may reference a body diagonal using its starting position, for example +X+Y–Z is the diagonal that goes from +X+Y–Z to –X–Y+Z. An alternative nomenclature using NNP (for X positive, Y negative, Z positive, direction of travel) is also acceptable.

See Figure 1.

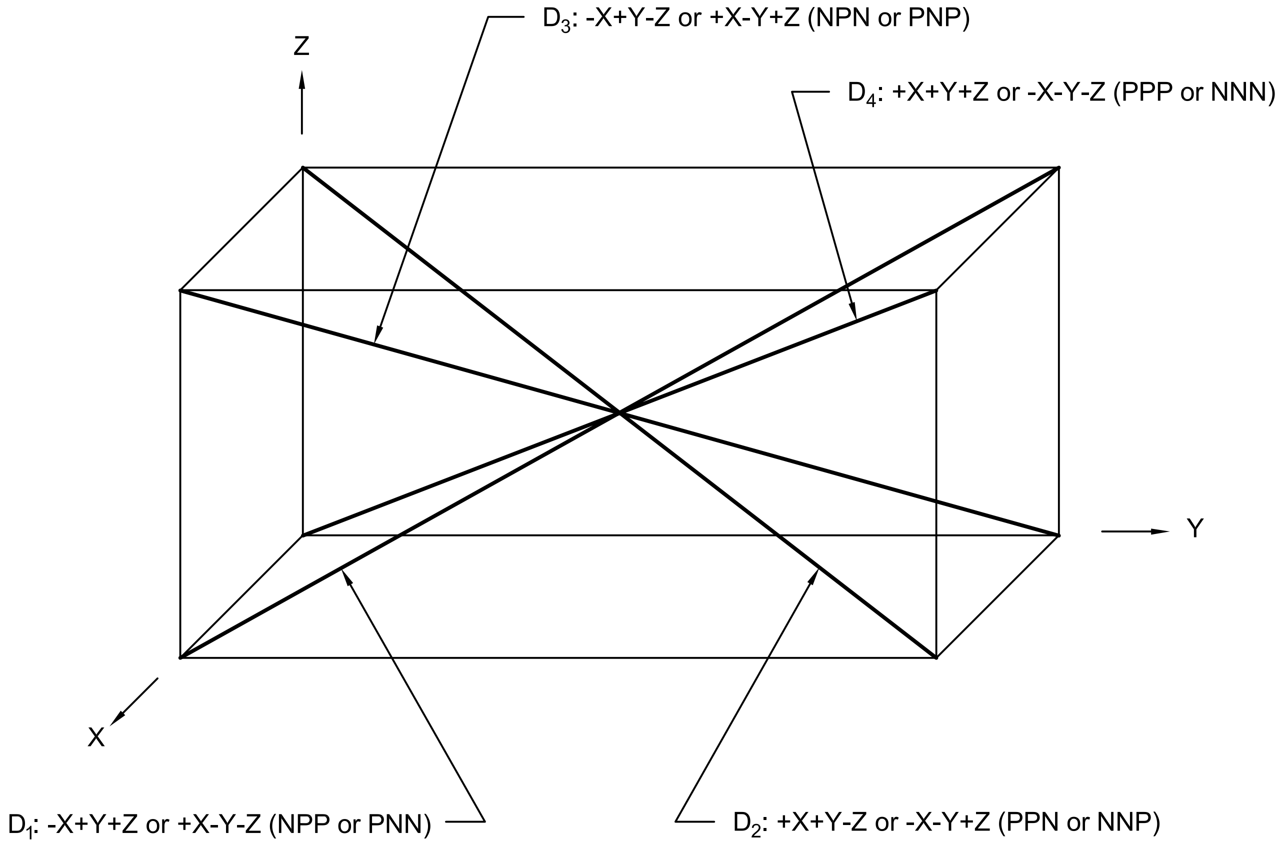

Figure 1 — Four body diagonals of a rectangular prism

3.3
face diagonal
F
diagonal in a face plane of a rectangular prism within the working volume of a machine tool

NOTE 1 Six different types of face diagonal may be defined within the working volume. For each diagonal selected, it is necessary to define further its location in the third axis. Ideally, the plane of the face diagonals should be either an external face or a central slice, as shown in Figure 2.

NOTE 2 The user may reference a face diagonal using its start position, for example +X–Y is the diagonal that goes from +X–Y to –X+Y. To define the third axis, the form +X –Y Z300 may be used to define an XY diagonal at Z = 300. An alternative nomenclature using NP or NP300 (for X negative, Y positive, Z missing, directions of travel) is also acceptable.

NOTE 3 Face diagonals are usually selected in crossed pairs for each plane as shown in Figure 2.

See Figure 2.

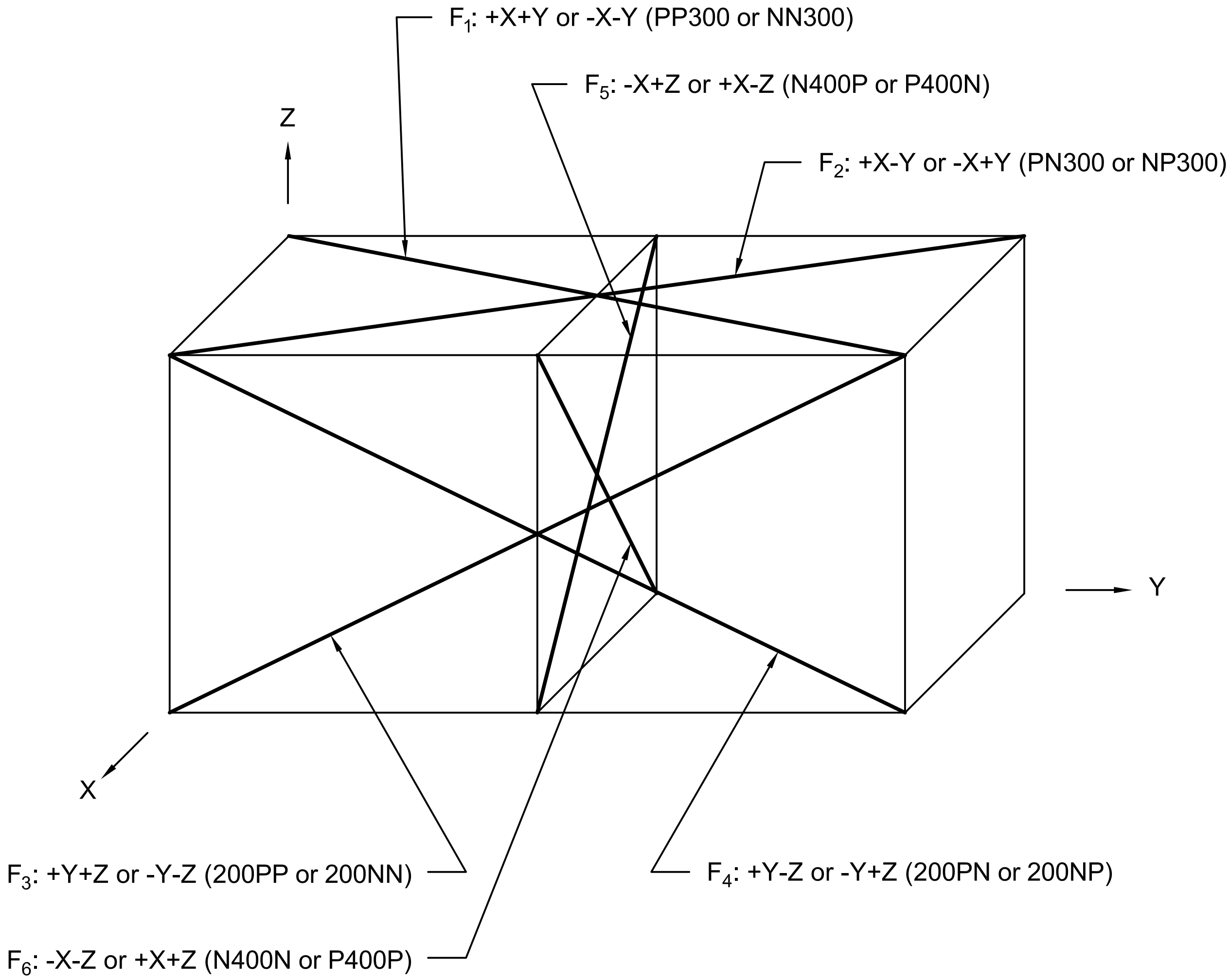

Figure 2 — Examples of face diagonals of a rectangular prism

3.4
diagonal systematic deviation of positioning
E_d
maximum bidirectional systematic deviation of positioning (in accordance with ISO 230-2) of the four body diagonals, E_1, E_2, E_3, E_4 (evaluation of E_i, see Figure 3)

$E_d =$ max. [E_1], E_2, E_3, E_4

3.5
diagonal systematic deviation of positioning in face diagonals
E_d (ab)
maximum bidirectional systematic deviation of positioning (in accordance with ISO 230-2) of the two face diagonals, E_1(ab), E_2(ab), where “ab” defines the coordinate plane of measurement

EXAMPLE E_d(XY) = max. [E_1(XY), E_2(XY)] for the two face diagonals in the XY plane.

3.6
diagonal reversal value
B_d
maximum reversal value (in accordance with ISO 230-2) of the four body diagonals, B_1, B_2, B_3, B_4 (evaluation of B_i see Figure 3)

B_d = max. [B_1, B_2, B_3, B_4]

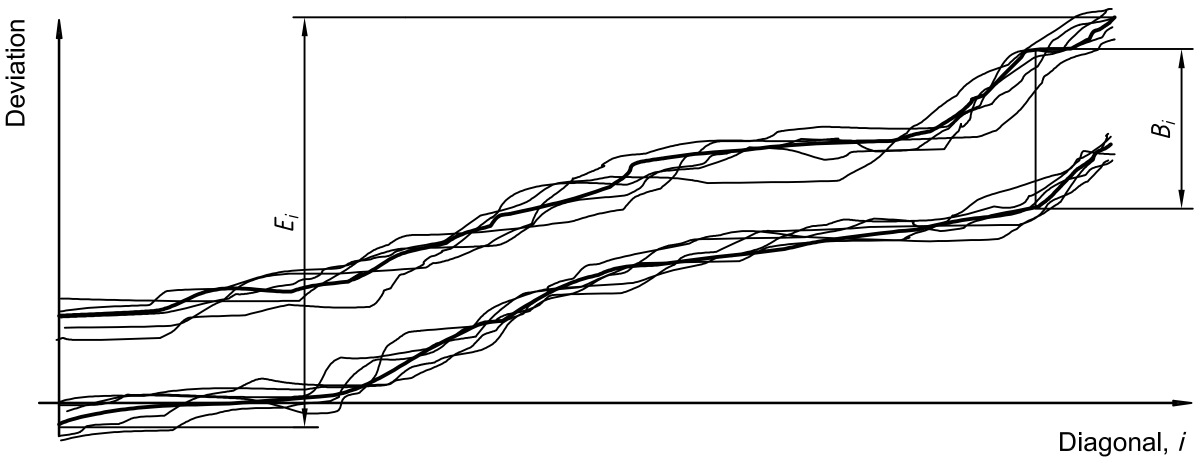

Figure 3 — Evaluation of E_i and B_i

3.7
diagonal reversal value for face diagonals
B_d(ab)
maximum reversal value (in accordance with ISO 230-2) in the two face diagonals, B_1(ab), B_2(ab), where "ab" defines the coordinate plane of measurement

EXAMPLE B_d(XY) = max. [E_1(XY), E_2(XY)] for the two face diagonals in the XY plane.

3.8
volumetric performance
ability of a machine tool to perform the intended multi-axes functions anywhere within the working volume or a smaller volume as agreed between manufacturer/supplier and user

NOTE Indication for reduced volume shall be by wording "reduced volume" after any parameter stated, e.g. E_d (reduced volume) = 0,012 mm.

4 Preliminary remarks

4.1 Measuring units

In this part of ISO 230, all linear dimensions are expressed in millimetres.

4.2 Reference to ISO 230-1 and ISO 230-2

To apply this part of ISO 230, reference should be made to ISO 230-1, especially for the installation of the machine before testing, warming-up of moving parts and recommended accuracy of test equipment.

Reference should also be made to ISO 230-2, especially for set-up and instrumentation, evaluation of results and presentation of results.

4.3 Tests to be performed

When testing a machine it is not always necessary, or possible, to carry out all the tests described in this part of ISO 230. When the tests are required for acceptance purposes, it is up to the user to choose, in agreement with the supplier/manufacturer, those tests relating to the features which are of interest to him, or relating to the components forming parts of the machine. Nevertheless these tests shall be clearly stated when ordering a machine and submitted to agreement as to the resulting expenses.

A solitary reference to this part of ISO 230 for acceptance tests, without agreement on the tests to be applied and on the resulting expenses, cannot be considered binding on any contracting party.

4.4 Measuring instruments

Laser interferometer or other measuring systems with comparable accuracy may be used (see 2.2 of ISO 230-1:1996).

4.5 Position of linear axes not under test

The position of the axis slides or moving components on the axes that are not under test shall be stated in the test sheet.

4.6 Measurement uncertainty

The measurement uncertainty is influenced by

— the uncertainties of the measuring instruments used for a single test;

— the uncertainties of possible alignments of the measuring instruments (dead path error, cosine error; see clause A.13 of ISO 230-1:1996);

— the uncertainties due to environmental influences, e.g. temperature influences (see clause 4 of ISO 230-3:2001).

The combined measurement uncertainty of a test should not be larger than a portion of the tolerance. The permissible portion should be agreed upon between the supplier/manufacturer and the user.

5 Test procedure, parameters, set-up procedure

5.1 Test procedure

The test procedure is conceptually similar to that described in ISO 230-2 for linear axes, except that linear displacements are not measured parallel to a linear axis, but along the diagonal of the working volume or plane of the machine tool.

NOTE On machines where one of the axes is much larger than the others, the diagonal displacement tests can be insensitive to certain systematic machine deviations.

The measurements shall be carried out along the four body diagonals (see Figure 1) of the working volume of a three-dimensional machine, and the two face diagonals of a two-dimensional machine (e.g. turning machine). Additionally, any or all of the six face diagonals of a three-dimensional machine (see Figure 2) may be carried out as required or as agreed between the supplier/manufacturer and the user.

5.2 Target positions

A minimum of five equally spaced target positions per metre diagonal length with an overall minimum of five target positions shall be selected.

If P_1 and P_2 are the end-points of a diagonal obtained after setting up the equipment and the desired diagonal increment is I_d then:

$$P_1 = (X_1, Y_1, Z_1)$$

$$P_2 = (X_2, Y_2, Z_2)$$

Length of diagonal = D

where

$$D = P_2 - P_1 = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2}$$

Length of path in X is X_v

where

$$X_v = X_2 - X_1$$

Incremental move is I_x

where

$$I_x = \frac{I_d}{D} X_v$$

Paths and increments in Y and Z are defined similarly. Programming is best achieved using incremental moves in the three axes using the quantities defined above. The end-point P_2 and the diagonal increment I_d may finally need to be modified to allow for rounding errors.

5.3 Measurements

Measurements shall be made at all the target positions according to the standard test cycle (see 4.3 of ISO 230-2:1997). Each target position shall be attained five times in each direction.

NOTE Diagonals up to 2 000 mm are not treated differently from diagonals exceeding 2 000 mm, because no repeatability values are calculated, but only the systematic deviation E, and the reversal value B.

5.4 Feed rate

The feed rate between the target positions shall be agreed upon between the supplier/manufacturer and the user, as shall the other parameters of the test. However, the feed rate shall not exceed 20 % of the maximum feed rate.

5.5 Set-up procedure

The measuring instrument is set up approximately in a diagonal of the working volume. The start point and the end point are aligned by moving the machine tool by using the jog command, in order to obtain a measuring signal. Between these two points, the machine tool is programmed to vector traverse, stopping at the target positions.

A detailed set-up procedure for a laser interferometer is described in annex A.

6 Evaluation of results

The data obtained for each of the diagonals shall be analysed in a manner conceptually similar to that used for the linear axes in accordance with ISO 230-2, with the exception that only the bi-directional systematic deviation E, and the reversal value B are evaluated (see Figure 3).

7 Points to be agreed between supplier/manufacturer and user

The points to be agreed between the supplier/manufacturer and the user are as follows:

a) the maximum rate of environmental temperature gradient in degrees per hour for 12 h before and during the measurements (see 3.1 of ISO 230-2:1997);

b) the location of the measuring instrument and the positions of the temperature sensors, if relevant (see 4.3.1 of ISO 230-2:1997);

c) the warming-up process to precede testing the machine (see 3.3 of ISO 230-2:1997);

d) the feed rate between target positions;

e) position of the slides or moving components which are not under test;

f) dwell time at each target position;

g) location of first and last target positions;

h) portion of tolerance which the combined measurement uncertainty of the test shall not exceed;

i) if relevant, size and position of reduced volume.

8 Presentation of the results

8.1 Method of presentation

The preferred method of presentation of the results is a graphical one, with at least the $E\uparrow$ and $E\downarrow$ graphs for each diagonal, and with the following list of items recorded in the test report to identify the measurement set-up:

— position of all elements of the measuring system relative to workholding and toolholding side;

— if relevant, position of the temperature sensor(s) on the machine components and the type of compensation routine;

— date of test;

— machine name, type (horizontal spindle or vertical spindle) and its coordinate travels;

— list of the test equipment used, including supplier/manufacturer's name, type and serial number of component;

— type(s) of machine scale used for positioning of axes and their coefficient(s) of thermal expansion used for nominal differential expansion (NDE) correction (e.g. ball screw and rotary resolver for Z axis, glass scale for X and Y axes);

— names of axes under test;

— feed rate and dwell time at each target position;

— first and last target points (P_1 and P_2) and diagonal increment (I_d);

— warming-up process to precede testing the machine (number of cycles or idling time and feed rate);

— temperatures of sensors attached to the relevant components of the machine representing machine scales and workpiece, at least at the start and end of the test;

— if relevant, air pressure and humidity at the start and end of the test;

— whether or not built-in compensation routines were used during the test cycle;

— use of air- or oil-shower, when applied;

— combined measurement uncertainty of the test;

— if relevant, size and position of reduced volume.

8.2 Parameters

The following parameters shall be specified numerically.

a) Parameters for body diagonals:

- — bi-directional systematic deviations of positioning, E_1, E_2, E_3, E_4;
- — reversal values, B_1, B_2, B_3, B_4;
- — diagonal systematic deviation of positioning, E_d;
- — diagonal reversal value, B_d.

b) Parameters for face diagonals:

- — bi-directional systematic deviations of positioning, E_1(ab), E_2(ab);
- — reversal values, B_1(ab), B_2(ab);
- — diagonal systematic deviation of positioning for face diagonals, E_d(ab);
- — diagonal reversal value for face diagonals, B_d(ab).

Annex A
(informative)

Set-up procedure for laser interferometer

A.1 General

This annex describes an example of an acceptable set-up procedure for a laser interferometer for diagonal displacement tests.

A.2 Procedure

First place the laser head, remote interferometer, and adjustable mirror on the table such that the adjustable mirror is at the corner of the table and the retroreflector in the spindle. (If the working volume extends beyond the table area, additional fixturing may be necessary.) In the case of a polarizing interferometer system, it is best if the adjustable mirror is placed between the remote interferometer and the retroreflector in the spindle. The interferometer should be placed as near as possible to the adjustable mirror to minimize dead path error. Alternatively, the adjustable mirror shall only be used to pitch or yaw the beam trajectory, and not both simultaneously. This is to avoid disturbing the laser beam polarizations. Note that the retroreflector is placed on the spindle centreline to reduce sensitivity to spindle axis roll, and the spindle should be locked. If the spindle cannot be locked, brackets should be used. On some horizontal machines it may be necessary to space the retroreflector away from the spindle nose to prevent the spindle carrier from interfering with the beam. In most practical cases, results should be referred back to 20 °C by the use of a material temperature sensor. The sensor shall be placed at the centre of the workholding site.

Next adjust the angle of the adjustable mirror such that the laser beam approximately traverses a body diagonal of the working area.

Move the machine spindle with the retroreflector to the nominal position desired for the end of the body diagonal being measured and adjust the beam with the adjustable mirror in order to obtain rough alignment. At this stage make sure that the outgoing beam is positioned on the adjustable mirror such that there is sufficient room for the return beam on the mirror face.

Next bring the machine spindle with the retroreflector to the closest point of approach to the adjustable mirror and, using the jog command, move the spindle until correct beam return alignment is obtained. Record the machine position.

Now move the machine to the furthest position along the body diagonal where measurement is desired and, again using the jog command, position the machine so that the correct beam return alignment is realised. For best results this position should be within 6 mm of the nominal position originally desired. Record this position.

Finally write the NC program to vector traverse the machine between these two machine points plus a short turn-around distance, with the prescribed intervals between the target positions and number of approaches required for data acquisition. Care needs to be taken to ensure the NC program does not include any rounding errors which may accumulate if a sequence of identical incremental moves is used to traverse the diagonal.

The set-up procedure for measuring face diagonals is similar to the above except that is essential that no movement in the third axis should occur. This means initially setting up the laser beam parallel to the test plane before adjusting the end-points. For example, to measure an XY face diagonal, the laser should first be set for either X or Y as for normal linear testing. This ensures that no Z movement will occur when the end points are adjusted for XY.

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