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Geometrical product specifications (GPS) — Guidelines for the evaluation of coordinate measuring machine (CMM) test uncertainty

Spécification géométrique des produits (GPS) — Lignes directrices pour l'estimation de l'incertitude d'essai des machines à mesurer tridimensionnelles (MMT)

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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 2.

The main task of technical committees is to prepare International Standards. 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.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

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

ISO/TS 23165 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

Introduction

This Technical Specification belongs to the general Geometrical product specification (GPS) series of documents (see ISO/TR 14638). It influences chain link 5 of the chains of standards on size, distance, radius, angle, form, orientation, location, run-out and datums in the general GPS matrix.

For more detailed information about the relationship of this Technical Specification to other standards and to the GPS matrix model, see Annex D.

ISO 10360-2 deals with the application of the ISO 14253-1 decision rule, which proves conformance or non-conformance of a coordinate measuring machine (CMM) that is accepted or re-verified with its specification. In turn, this decision rule is based on a statement of the measurement uncertainty incurred while testing, and hence requires a full evaluation of the test uncertainty. This uncertainty expresses how accurate the test is, and hence how narrow the safety margins need to be set in order to make a rational decision at a specified confidence level.

Usual practice in CMM measurement familiarizes metrologists and practitioners with measurement uncertainty. Any possible effect which may affect the measurement result is considered and quantified as an uncertainty contributor, and eventually summed up to achieve the combined uncertainty. The purpose of the measurement is to gather quantitative information on a given measurand, and the uncertainty statement expresses how reliable that information is.

In the case of a performance test of a CMM, the purpose of the measurement is to investigate the CMM's performance rather than the form or size of a material standard, which is calibrated and therefore well-known in advance. The uncertainty being evaluated in this case quantifies how accurate the test is. The test detects the quality of the CMM by comparing the measurement test values with the known calibrated values of the material standards of size (probing error, P, or error of indication, E), and not through the uncertainty statement.

Consequently, only those uncertainty components that pertain to the test itself are included in the test uncertainty budget as contributors. In particular, instrumental errors introduced by the CMM are not included in the budget. In total, they constitute the probing error, P, or the error of indication, E, but do not compromise the test reliability and hence are not contributors to the test uncertainty.

From a different viewpoint, the ISO 14253-1 principle is that it is always the person performing the measurement who is liable for the uncertainty, whether in proving conformance or non-conformance. In other words, the tester is responsible for any imperfection which may occur during the test, and he takes this into account in terms of test uncertainty. A corollary of this is that the tester should only be held accountable for the elements under his responsibility, i.e. only these elements should be included in the test uncertainty budget. As the ISO 10360-2 test is not necessarily performed by the CMM manufacturer, the tester does not have any responsibility for the CMM instrumental errors. For example, a purchaser may want to prove that a CMM with large errors falls outside specification; if the CMM errors were to be considered in the budget, the resulting test uncertainty would be so large that it probably could not prove anything at all. When the test is performed by a CMM manufacturer, the latter, as the tester, takes responsibility for any imperfection in the test implementation with the test uncertainty — which narrows the acceptance zone —, and, as the manufacturer, takes responsibility for any imperfection of the CMM regarding any large values of the probing error, P, and error of indication, E.

Geometrical product specifications (GPS) — Guidelines for the evaluation of coordinate measuring machine (CMM) test uncertainty

1 Scope

This Technical Specification gives guidance for the application of the test described in ISO 10360-2, by explaining the evaluation of the test uncertainty required for ISO 14253-1.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1:2002, *Geometrical Product Specifications (GPS) — Standard reference temperature for geometrical product specification and verification*

ISO 3650:1998, *Geometrical Product Specifications (GPS) — Length standards — Gauge blocks*

ISO 10360-1:2000, *Geometrical Product Specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 1: Vocabulary*

ISO 10360-2:2001, *Geometrical Product Specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 2: CMMs used for measuring size*

ISO 14253-1:1998, *Geometrical Product Specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 1: Decision rules for proving conformance or non-conformance with specifications*

ISO/TS 14253-2:1999, *Geometrical Product Specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 2: Guide to the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification*

ISO 14660-1:1999, *Geometrical Product Specifications (GPS) — Geometrical features — Part 1: General terms and definitions*

ISO/TS 17450-2:2002, *Geometrical product specifications (GPS) — General concepts — Part 2: Basic tenets, specifications, operators and uncertainties*

International vocabulary of basic and general terms in metrology (VIM), BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 2nd ed., 1993

Guide to the expression of uncertainty in measurement (GUM), BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1993, corrected and reprinted in 1995

3 Terms and definitions

For the purpose of this Technical Specification, the definitions given in ISO 10360-1, ISO 14660-1, ISO 14253-1, ISO/TS 17450-2, VIM and the following apply.

3.1
test uncertainty
expanded uncertainty, U, associated solely with the testing equipment and its use in the test, which modifies the conformance and non-conformance zones, in accordance with the decision rule in ISO 14253-1

NOTE 1 Test uncertainty is a measure of the quality of the testing equipment and its use in the test. It is not a measure of CMM performance, which is determined from probing error, P, and error of indication for size measurement, E.

NOTE 2 Test uncertainty is controlled by and is the responsibility of the tester, who provides and uses the test equipment and suffers a reduced conformance or non-conformance zone in the case of a large test uncertainty.

3.2
tester
party who performs the test defined in the ISO 10360-2

NOTE 1 In an acceptance test, the tester can be either the supplier or the customer, possibly represented by a third party.

NOTE 2 In a reverification test, the tester is the user, possibly represented by a third party.

NOTE 3 The tester is always responsible for the test uncertainty.

3.3
tester counterpart
party other than the tester

NOTE 1 In an acceptance test, the tester counterpart can be either the customer or the supplier, possibly represented by a third party.

NOTE 2 In a reverification test, the tester counterpart is the user himself, possibly represented by a third party.

3.4
coefficient of thermal expansion
CTE
⟨material standard of size⟩ coefficient of thermal expansion of a material at 20 °C

NOTE For the purpose of this Technical Specification, only the CTE of the material standard of size is considered.

4 General

This Technical Specification provides simplified equations for the test uncertainty of the quantities tested in accordance with ISO 10360-2 (i.e. the probing error, P, and the error of indication, E), and is intended as a quick reference for application. More detailed information is given in Annex A, which provides the general error models from which the simplified equations are derived, as well as some discussion of the nature of each uncertainty component, guidance on how to keep it to a minimum, and how to estimate its input uncertainty. In addition, possible uncertainty contributors are listed. Even if the main body alone may suffice for day-to-day use, a careful reading of Annex A is recommended for background information, as well as for typical applications.

The simplified equations for test uncertainty, which are given in this Technical Specification for the main uncertainty contributors, are representative in most common circumstances. They are, however, limited to these circumstances and may be inadequate in a particular case. A careful analysis of the actual circumstances is recommended in order to ascertain whether a given contributor listed in Annex A is in fact negligible, or not.

Once the combined standard uncertainties $u(P)$ or $u(E)$ are evaluated in accordance with the simplified equations, the expanded uncertainty $U(P)$ or $U(E)$ are obtained through multiplication by a coverage factor, k, as follows:

$$U(P) = k \times u(P) \tag{1}$$

and

$$U(E) = k \times u(E) \tag{2}$$

The value $k = 2$ shall be used.

Annex B deals with the special case when the material standard of size is offered by the tester counterpart.

Fully developed numerical examples are given in Annex C.

5 Test probing error

The recommended equation for the standard uncertainty of the probing error, $u(P)$, is

$$u(P) = \sqrt{\left(\frac{F}{2}\right)^2 + u^2(F)} \tag{3}$$

where

F is the form error reported in the calibration certificate

$u(F)$ is the standard uncertainty of the form error stated in the calibration certificate

The expanded uncertainty, U, reported in the certificate shall be transformed into the standard uncertainty, u, by dividing by the coverage factor, k, $u = U/k$. The value of k is also reported in the certificate, the most common value being $k = 2$.

NOTE Insufficient rigidity of the test sphere can cause additional errors in the value of P, which are not accounted for in the uncertainty equation above (see A.2.2 for details).

6 Test of size

6.1 General

The recommended equation for the standard uncertainty of the error of indication, $u(E)$, is

$$u(E) = \sqrt{u^2(\varepsilon_{\text{cal}}) + u^2(\varepsilon_\alpha) + u^2(\varepsilon_t) + u^2(\varepsilon_{\text{align}}) + u^2(\varepsilon_{\text{fixt}})} \tag{4}$$

where

ε_{cal} is the calibration error of the material standard of size;

ε_α is the error due to the input value of the CTE of the material standard of size;

ε_t is the error due to the input value of the temperature of the material standard of size;

$\varepsilon_{\text{align}}$ is the error due to misalignment of the material standard of size;

$\varepsilon_{\text{fixt}}$ is the error due to fixturing the material standard of size.

6.2 Analysis of the uncertainty contributors

6.2.1 Uncertainty due to the calibration of the material standards of size, $u(\varepsilon_{cal})$

The recommended equation for this uncertainty component is

$$u(\varepsilon_{cal}) = \frac{U_{cal}}{k} \qquad (5)$$

where

U_{cal} is the expanded calibration uncertainty of the material standard of size reported in the calibration certificate;

k is the coverage factor of U_{cal}, reported in the calibration certificate.

NOTE A typical value of the coverage factor is $k = 2$.

6.2.2 Uncertainty due to the CTE of the material standard of size, $u(\varepsilon_\alpha)$

This uncertainty component should be considered only when the CMM requires the tester to input a CTE value. Hence, it should be discarded for thermally-uncompensated CMMs, i.e. the value $u(\varepsilon_\alpha) = 0$ should be used in Equation 4.

The recommended equation for this uncertainty component is

$$u(\varepsilon_\alpha) = L \times (|t - 20\ °C|) \times u(\alpha) \qquad (6)$$

where

L is the size of the material standard being measured;

t is the temperature of the material standard of size, when measured;

20 °C is the reference temperature (see ISO 1);

$u(\alpha)$ is the standard uncertainty of the CTE of the material standard of size.

The value of t in Equation 6 should be measured or estimated for each test position.

To evaluate the input uncertainty $u(\alpha)$, the following procedures are suggested.

— If the material standard of size has been calibrated for its CTE, the uncertainty reported in the calibration certificate should be taken. The expanded uncertainty, U, reported in the certificate shall be transformed into the standard uncertainty, u, by dividing by the coverage factor k, $u = U/k$. The value of k is also reported in the certificate, the most common value being $k = 2$.

— If the CTE of the standard has not been calibrated, technical literature may report typical ranges of values for the material of the standard of size. If so, the span, T_α, should be divided by the square root of 12, $u(\alpha) = T_\alpha / \sqrt{12}$.

— In the particular case of steel gauge blocks, ISO 3650 specifies a range $\alpha = (11{,}5 \pm 1) \times 10^{-6}\ K^{-1}$, and therefore a value of $u(\alpha) = 0{,}58 \times 10^{-6}\ K^{-1}$ should be taken if no individual calibration value is available.

6.2.3 Uncertainty due to the input temperature of the material standards of size, $u(\varepsilon_t)$

This uncertainty component should be considered only for thermally-compensated CMMs, and only when the compensation relies on the temperature of the material standard of size, as measured by the tester by means of his own thermometers. When the temperature is measured by means of CMM-embedded thermometers, or when a CMM is not thermally compensated, this uncertainty component should be discarded, i.e. a value $u(\varepsilon_t) = 0$ should be used in Equation 4.

The recommended equation for this uncertainty component is

$$u(\varepsilon_t) = L \times \alpha \times u(t) \tag{7}$$

where

L is the size of the material standard being measured;

α is the CTE of the material standard of size;

$u(t)$ is the standard uncertainty of the temperature of the material standard of size.

To evaluate the input uncertainty $u(t)$, the following components are suggested for consideration.

— The calibration uncertainty of the thermometer(s) used is reported in the calibration certificate of the thermometer(s). The expanded uncertainty, U, reported in the certificate shall be transformed into the standard uncertainty, u, by dividing by the coverage factor, k, $u = U/k$. The value of k is also reported in the certificate, the most common value being $k = 2$.

— The uncertainty due to temperature variation during the test is best derived from experience with standards of similar thermal properties. In the absence of such experience, the approximate value $V_t/\sqrt{3}$ is recommended, where V_t is the span of the temperature difference between any two points on or in the material standard of size.

— When the recommendations in A.3.2.4 are followed, other uncertainty components are likely to be negligible.

The standard uncertainties obtained as above are summed in quadrature.

6.2.4 Uncertainty due to misalignment of the material standard of size, $u(\varepsilon_{\text{align}})$

It is recommended that care be taken to keep this component to a minimum. A.3.2.5 gives guidance on good metrological practice in this respect. When this guidance is followed, the component is likely to be negligible, i.e. a value $u(\varepsilon_{\text{align}}) = 0$ should be used in Equation 4.

However, this may not be true in all cases. A careful reading of A.3.2.5 is recommended to ascertain whether the actual circumstances determine a non-zero contributor, and, if so, to model and evaluate it.

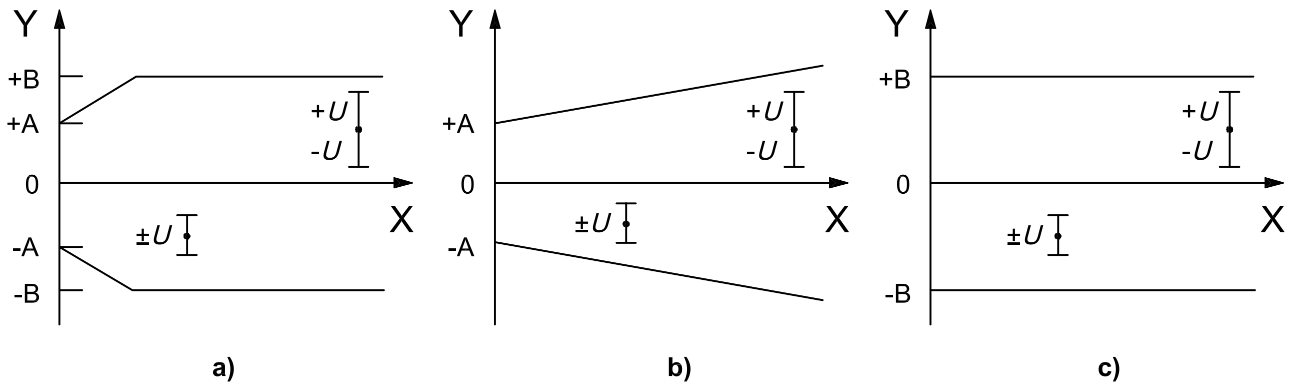
6.2.5 Uncertainty of fixturing the material standard of size, $u(\varepsilon_{\text{fixt}})$

It is recommended that all care be taken to keep this component to a minimum. A.3.2.6 gives guidance on good metrological practice in this respect. When this guidance is followed, the component may be negligible, i.e. a value $u(\varepsilon_{\text{fixt}}) = 0$ should be used in Equation 4.

However, this may not be true in all cases. A careful reading of A.3.2.6 is recommended to ascertain whether the actual circumstances determine a non-zero contributor, and, if so, to model and evaluate it.

6.3 Graphical representation of the test results

In accordance with ISO 10360-2:2001, 5.3.4, the values of E obtained should be plotted in a diagram (see Figures 1 and 2). Two alternative and equivalent representations are possible to deal with the test uncertainty, $U(E)$ (see ISO 14253-1:1998, Figures 6 to 11).



Key

X size, L, expressed in millimetres, of the material standard being measured

Y error of indication, E, expressed in micrometres

A positive constant, expressed in micrometres and supplied by the manufacturer

B maximum permissible error MPE_E, expressed in micrometres, as stated by the manufacturer

U expanded uncertainty

NOTE 1 Points with bars represent the values of E, and simple lines represent the MPE_E. The bar lengths represent the uncertainties $\pm U(E)$, and the central points represent the values obtained for the errors of indication.

NOTE 2 Only two values of E plotted for simplicity.

Figure 1 — Types of diagrams for the plotting of E, in accordance with ISO 10360-1:2000, 9.2