TECHNICAL SPECIFICATION

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Geometrical product specifications (GPS) — Guidelines for the evaluation of coordinate measuring machine (CMM) test uncertainty for CMMs using single and multiple stylus contacting probing systems

Spécification géométrique des produits (GPS) — Lignes directrices pour l'estimation de l'incertitude d'essai des machines à mesurer tridimensionnelles (MMT) pour MMT utilisant des systèmes de palpage à stylet simple et à stylets multiples

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

Introduction

This Technical Specification is a geometrical product specification (GPS) document and is to be regarded as a general GPS document (see ISO 14638). It influences chain links F of the chain of standards in the general GPS matrix model.

For more detailed information of the relation of this Technical Specification to the GPS matrix model, see Annex B.

The ISO GPS Matrix Model given in ISO 14638 gives an overview of the ISO GPS system of which this Technical Specification is a part. The fundamental rules of ISO GPS given in ISO 8015 apply to this Technical Specification. The default decision rules given in ISO 14253-1 apply to specifications made in accordance with this Technical Specification, unless otherwise stated.

This Technical Specification gives guidance for the evaluation of the test value uncertainty as required by the application of ISO 10360-5.

Before starting any test value uncertainty evaluation, it is recommended that

— the distinction between the *test value uncertainty* and the *measurement uncertainty* is fully understood (the former is used to reduce the acceptance zone in a test, the latter to quantify the reliability of a measurement value) and

— the principle of the tester’s responsibility in deciding whether or not to include an uncertainty component in the budget is also understood.

Some details of the above issues are given in ISO/TS 23165, the careful reading of which is recommended.

Geometrical product specifications (GPS) — Guidelines for the evaluation of coordinate measuring machine (CMM) test uncertainty for CMMs using single and multiple stylus contacting probing systems

1 Scope

This Technical Specification describes how to evaluate the test value uncertainty when testing is performed according to ISO 10360-5.

2 Normative references

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

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

ISO 10360-5:2010, *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 5: CMMs using single and multiple stylus contacting probing systems*

ISO 14253-1:—[1)], *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 1: Decision rules for proving conformity or nonconformity with specifications*

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

ISO/TS 23165, *Geometrical product specifications (GPS) — Guidelines for the evaluation of coordinate measuring machine (CMM) test uncertainty*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10360-1, ISO 10360-5, ISO 14253-1, ISO 17450-2, ISO/TS 23165, ISO/IEC Guide 98-3 and ISO/IEC Guide 99 apply.

1) To be published. (Revision of ISO 14253-1:2013)

4 Test value uncertainty evaluation

4.1 Effects of fixturing and bending of the test sphere stem

The following contributors may be relevant in some applications.

— Fixturing of the test sphere: if the test sphere is fixtured loosely or vibrations are present, the test sphere may shift during the measurements, due to, for example, probing forces, vibrations and inertial forces.

— Bending of the test sphere stem: if the test sphere stem is insufficiently rigid, the bending due to probing forces may be a significant source of test value uncertainty.

The influence of these effects can be measured using a displacement sensor (such as a precision indicator or capacitance gauge) when a force equivalent to the probing force (i.e., the force at the instant of point detection) is applied to the test sphere. The distance of this displacement is called $d_{\text{FIXTURING}}$ for the purposes of this Technical Specification.

Alternatively, two significantly different probing forces can be used to calculate the *P* values and then compared in order to assess these fixturing effects.

4.2 Form of the test sphere

The formulae that follow in the rest of Clause 4 make use of the form and the uncertainty of the form of the test sphere, which, according to ISO 10360-5:2010, 6.2.3, is to have been calibrated (the form of the test sphere is the same as its sphericity). It is the form of the test sphere (and not the roundness) that is to be calibrated. However, if the roundness of the sphere is calibrated instead of using traces about great circles of the sphere, then, upon agreement of buyer and seller, the roundness calibrations may be used to estimate the form and its uncertainty by using the adjustment factors as given in Annex A.

4.3 Test of the probing system form error

The recommended formula for the standard uncertainty of the probing error $u(P_{F--})$ is Formula (1):

$$u\left(P_{F--}\right)=\sqrt{\left(\frac{F_{\text{SPHERE}}}{2}\right)^2+u^2\left(F_{\text{SPHERE}}\right)+\left(\frac{d_{\text{FIXTURING}}}{2}\right)^2} \qquad (1)$$

where

F_{SPHERE}	is the form of the test sphere;
$u\left(F_{\text{SPHERE}}\right)$	is the standard uncertainty in the form of the test sphere stated in the calibration certificate;
$d_{\text{FIXTURING}}$	is the displacement due to the probing force.

The one-sided nature of this test means that the typical 95 % confidence level is achieved with a coverage factor of k = 1,645 instead of the usual k = 2 (the default value given in ISO 14253-1:—, Clause 4), which applies to two-sided distributions.

The standard uncertainty, u, for the form calibration is found by dividing the expanded uncertainty U reported in the form calibration certificate by the coverage factor k, $u = U/k$; the value of k is also reported in the certificate.

NOTE The above standard uncertainty formula for $u(P_{F\text{--}})$ can be an overestimate (see ISO 14253-2) due to the unknown, complex interaction between the form of the test sphere with the error behaviour during probing. This overestimation is not problematic for many cases, but in some cases can be problematic when the form of an available and/or affordable test sphere is not sufficiently small in comparison with the maximum permissible limit of the $P_{F\text{--}}$ value. In this case, the buyer and seller might agree on an acceptable way to proceed, considering possibilities such as the following:

— a different decision rule may be agreed upon based on ISO/TR 14253-6;

— a technically correct, more detailed formula for the test value uncertainty is obtained.

4.4 Test of the probing system size value

The recommended formula for the standard uncertainty of the error of indication $u(P_{S\text{--}})$ is Formula (2):

$$u\left(P_{S--}\right)=\sqrt{u^2\left(D_{\text{cal}}\right)+\left(\alpha u\left(T\right)D_{\text{cal}}\right)^2+\left(\Delta T u\left(\alpha\right)D_{\text{cal}}\right)^2+\left(\frac{F_{\text{SPHERE}}}{4}\right)^2+\left(\frac{u\left(F_{\text{SPHERE}}\right)}{2}\right)^2+\left(\frac{d_{\text{FIXTURING}}}{2}\right)^2} \quad (2)$$

where

D_{cal}	is the calibrated diameter of the test sphere;
$u\left(D_{\text{cal}}\right)$	is the standard uncertainty in the calibrated diameter of the test sphere;
α	is the CTE of the test sphere material;
$u\left(\alpha\right)$	is the standard uncertainty in the CTE of the test sphere material;
ΔT	is the temperature of the test sphere minus 20 °C;
$u\left(T\right)$	is the standard uncertainty of the temperature of the test sphere;
F_{SPHERE}	is the form of the test sphere;
$u\left(F_{\text{SPHERE}}\right)$	is the standard uncertainty in the form of the test sphere stated in the calibration certificate;
$d_{\text{FIXTURING}}$	is the displacement due to the probing force.

4.5 Test of the probing system location value

The recommended formula for the standard uncertainty of the location value $u(P_{L--})$ is Formula (3):

$$u\left(P_{L--}\right)=\sqrt{\left(\frac{F_{\text{SPHERE}}}{2}\right)^2+u^2\left(F_{\text{SPHERE}}\right)+\left(d_{\text{FIXTURING}}\right)^2} \quad (3)$$

where

F_{SPHERE}	is the form of the test sphere;
$u\left(F_{\text{SPHERE}}\right)$	is the standard uncertainty in the form of the test sphere stated in the calibration certificate;
$d_{\text{FIXTURING}}$	is the displacement due to the probing force.

Annex A
(informative)

Using roundness to approximate form

A.1 Problem and proposed solution

The formulae given in this Technical Specification make use of the form of the test sphere along with the uncertainty in the form. Practically, many test spheres are calibrated for roundness rather than form. That is, the roundness is measured for each of a number of great circles traced out on the surface of the sphere, and the largest of these is reported as a representation of the form.

In this case, one cannot directly use the formula, since the form is not fully captured by the roundness. The purpose of Annex A is to provide guidance in this situation.

Two common patterns arising for imperfections in a sphere are a four-lobed form (where the lobes are centred at the vertices of a regular, inscribed tetrahedron) and a two-lobed form (a prolate spheroid). For these cases, simulation studies were performed to ascertain what fraction of the form is captured when measuring the roundness on great circles (the orientation of the form pattern was randomized through the simulation). Adjustment factors have been computed and reported here to adjust from roundness to form (using the worse of the four-lobed and two-lobed cases).

While this approach admittedly falls short of all the form effects that can be seen in reality, as is written in 4.2, if buyer and seller agree, they may proceed using the adjustments given in Annex A.

In the formulae in Annex A, the following meanings hold:

F_{SPHERE}	is the form of the test sphere estimated by the equations below;
$u(F_{\text{SPHERE}})$	is the standard uncertainty in the form estimated by the equations below;
R_{SPHERE}	is the roundness of the test sphere (or the maximum roundness in the case of multiple circular traces);
$u(R_{\text{SPHERE}})$	is the standard uncertainty in the roundness of the test sphere stated on the calibration certificate.

A.2 Three great circles

In the case where roundness is computed on three great circles, each being in a plane orthogonal to other two, the following adjustment factors are proposed as estimates:

$$F_{\text{SPHERE}} = 1{,}25\left(R_{\text{SPHERE}}\right) \tag{A.1}$$

$$u\left(F_{\text{SPHERE}}\right) = 1{,}25\left(u\left(R_{\text{SPHERE}}\right)\right) \tag{A.2}$$

A.3 Five great circles

In some cases, the roundness is computed on five great circles. If the sphere is mounted on a stem, the stem can be imagined being in the –Z direction of a coordinate system. Then, the pattern of five great circles is one parallel to the *XY* plane, and four in planes orthogonal to directions (1, 0, 1), (0, 1, 1), (−1, 0, 1) and (0, −1, 1). In this case, the following adjustment factors are proposed as estimates:

$$F_{\text{SPHERE}} = 1{,}1\left(R_{\text{SPHERE}}\right) \quad \text{(A.3)}$$

$$u\left(F_{\text{SPHERE}}\right) = 1{,}1\left(u\left(R_{\text{SPHERE}}\right)\right) \quad \text{(A.4)}$$

A.4 One great circle

In the case where one great circle is used to compute the roundness, it should be noted that this approach can drastically undersample the sphere, lacking sufficient coverage to capture many common forms. Since the adjustment found by simulation was large (namely, 10,5 for the case of the prolate spheroid), the opinion of the writers of this Technical Specification is that the roundness found using a single great circle should not be extrapolated into a form value.

Annex B
(informative)

Relation to the GPS matrix model

B.1 General

For full details about the GPS matrix model, see ISO 14638.

B.2 Information about this Technical Specification and its use

This Technical Specification gives guidance for the evaluation of the test value uncertainty as required by the application of ISO 10360-5.

B.3 Position in the GPS matrix model

This Technical Specification is a general GPS document, which influences chain link F of the chains of standards in the general GPS matrix model, as graphically illustrated in Table B.1.

Table B.1 — Position in the GPS matrix model

	Chain links						
	A	**B**	**C**	**D**	**E**	**F**	**G**
	Symbols and indications	Feature requirements	Feature properties	Conformance and non-conformance	Measurement	Measurement equipment	Calibrations
Size						•	
Distance						•	
Form						•	
Orientation						•	
Location						•	
Run-out						•	
Profile surface texture						•	
Areal surface texture						•	
Surface imperfections						•	

B.4 Related standards

The related standards are those of the chains of standards indicated in Table B.1.

Bibliography

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

[2] ISO 8015, *Geometrical product specifications (GPS) — Fundamentals — Concepts, principles and rules*

[3] ISO 14253-2, *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 2: Guidance for the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification*

[4] ISO 14253-5, *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 5: Uncertainty in verification testing of indicating measuring instruments*

[5] ISO 14638, *Geometrical product specifications (GPS) — Matrix model*

[6] ISO/TR 14253-6, *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 6: Generalized decision rules for the acceptance and rejection of instruments and workpieces*

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