TECHNICAL SPECIFICATION

ISO/TS 14253-2

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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

Spécification géométrique des produits (GPS) — Vérification par la mesure des pièces et des équipements de mesure —

Partie 2: Guide pour l'estimation de l'incertitude dans les mesures GPS, dans l'étalonnage des équipements de mesure et dans la vérification des produits

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 734 10 79
E-mail copyright@iso.ch
Web www.iso.ch

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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.

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 every three years with a view to deciding whether it can be transformed into an International Standard.

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

ISO/TS 14253-2 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

ISO 14253 consists of the following parts, under the general title *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment*:

— *Part 1: Decision rules for proving conformance or non-conformance with specification*

— *Part 2: Guide to the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification* [Technical Specification]

— *Part 3: Procedures for evaluating the integrity of uncertainty in measurement values*

Annexes A to D of this Technical Specification are for information only.

Introduction

This Technical Specification is a global GPS technical report (see ISO/TR 14638:1995). This global GPS Technical Report influences chain link 4, 5 and 6 in all chains of standards.

For more detailed information of the relation of this report to other standards and the GPS matrix model, see annex D.

This Technical Specification is developed to support ISO 14253-1. This Technical Specification establishes a simplified, iterative procedure of the concept and the way to evaluate and determine uncertainty (standard uncertainty and expanded uncertainty) of measurement, and the recommendations of the format to document and report the uncertainty of measurement information as given in *"Guide to the expression of uncertainty in measurement"* (GUM). In most cases only very limited resources are necessary to estimate uncertainty of measurement by this simplified, iterative procedure, but the procedure may lead to a slight overestimation of the uncertainty of measurement. If a more accurate estimation of the uncertainty of measurement is needed, the more elaborated procedures of the GUM must be applied.

This simplified, iterative procedure of the GUM methods is intended for GPS measurements, but may be used in other areas of industrial (applied) metrology.

Uncertainty of measurement and the concept of handling uncertainty of measurement being of importance to all the technical functions in a company, this Technical Specification relates to e.g. management function, design and development function, manufacture function, quality assurance function, metrology function, etc.

This Technical Specification is of special importance in relation to ISO 9000 quality assurance systems, where it is a requirement that the uncertainty of measurement is known [e.g. 4.11.1, 4.11.2 a) and 4.11.2 b) of ISO 9001:1994].

In this Technical Specification the uncertainty of the result of a process of calibration and a process of measurement is handled in the same way:

— calibration is treated as "measurement of metrological characteristics of a measuring equipment or a measurement standard";

— measurement is treated as "measurement of geometrical characteristics of a workpiece".

Therefore, in most cases no distinction is made in the text between measurement and calibration. The term "measurement" is used as a synonym for both.

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

1 Scope

This Technical Specification gives guidance on the implementation of the concept of *"Guide to the estimation of uncertainty in measurement"* (in short GUM) to be applied in industry for the calibration of (measurement) standards and measuring equipment in the field of GPS and the measurement of workpiece GPS-characteristics. The aim is to promote full information on how to achieve uncertainty statements and provide the basis for international comparison of results of measurements and their uncertainties (relationship between purchaser and supplier).

This Technical Specification is intended to support ISO 14253-1. This Technical Specification and ISO 14253-1 are beneficial to all technical functions in a company in the interpretation of GPS specifications (i.e. tolerances of workpiece characteristics and values of maximum permissible errors (MPE) for metrological characteristics of measuring equipment).

This Technical Specification introduces the Procedure for Uncertainty MAnagement (PUMA), which is a practical, iterative procedure based on the GUM for estimating uncertainty of measurement without changing the basic concepts of the GUM and is intended to be used generally for estimating uncertainty of measurement and giving statements of uncertainty for:

- single results of measurement;
- comparison of two or more results of measurement;
- comparison of results of measurement — from one or more workpieces or pieces of measurement equipment — with given specifications [i.e. maximum permissible errors (MPE) for a metrological characteristic of a measurement instrument or measurement standard, and tolerance limits for a workpiece characteristic, etc.], for proving conformance or non-conformance with the specification.

The iterative method is based basically on an upper bound strategy, i.e. overestimation of the uncertainty at all levels, but the iterations control the amount of overestimation. Intentional overestimation — and not under-estimation — is necessary to prevent wrong decisions based on measurement results. The amount of overestimation shall be controlled by economical evaluation of the situation.

The iterative method is a tool to maximize profit and minimize cost in the metrological activities of a company. The iterative method/procedure is economically self-adjusting and is also a tool to change/reduce existing uncertainty in measurement with the aim of reducing cost in metrology (manufacture). The iterative method makes it possible to compromise between risk, effort and cost in uncertainty estimation and budgeting.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this Technical Specification. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this Technical Specification 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 1:1975, *Standard reference temperature for industrial length measurements*.

ISO 4288:1996, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Rules and procedures for the assessment of surface texture*.

ISO 9001:1994, *Quality systems — Model for quality systems in design, development, production, installation and servicing*.

ISO 9004-1:1994, *Quality management and quality system elements — Part 1: Guidelines*.

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

ISO 14253-3:—[1)], *Geometrical Product Specification (GPS) — Inspection by measurement of workpieces and measuring instruments — Part 3: Procedures for evaluating the integrity of uncertainty of measurement values.*

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

Guide to the expression of uncertainty in measurement (GUM). BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1st edition, 1995.

International Vocabulary of Basic and General Terms in Metrology (VIM). BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 2nd edition, 1993.

3 Terms and definitions

For the purposes of this Technical Specification, the terms and definitions given in ISO 14253-1, ISO 14660-1, VIM, GUM and the following apply.

3.1
black box model for uncertainty estimation
method of/model for uncertainty estimation in which the output value of a measurement is obtained in the same unit as the input (stimuli), rather than by measurement of other quantities functionally related to the measurand

NOTE 1 In the black box model — in this Technical Specification — the uncertainty components are assumed additive, the influence quantities is transformed to the unit of the measurand and the sensitivity coefficients are equal to 1.

NOTE 2 In many cases a complex method of measurement may be looked upon as one simple black box with stimulus in and result out from the black box. When a black box is opened, it may turn out to contain several "smaller" black boxes and/or several transparent boxes.

NOTE 3 The method of uncertainty estimation remains a black box method even if it is necessary to make supplementary measurements to determine the values of influence quantities in order to make corresponding corrections.

1) To be published.

3.2
transparent box model for uncertainty estimation
method of/model for uncertainty estimation in which the value of a measurand is obtained by measurement of other quantities functionally related to the measurand

3.3
measuring task
quantification of a measurand according to its definition

3.4
basic measurement task (basic measurement)
measurement task(s) which form the basis for evaluation of more complicated characteristics of a workpiece or a measuring equipment

NOTE Examples of a basic measurement are:

a) one of several individual measurements of the deviation from straightness of a feature of a workpiece;

b) one of the individual measurements of error of indication of a micrometer when measuring the range of error of indication.

3.5
overall measurement task
complicated measuring task, which is evaluated on the basis of several and maybe different basic measurements

NOTE Examples of an overall measuring task are:

a) the measurement of straightness of a feature of a workpiece;

b) the range of error of indication of a micrometer.

3.6
expanded uncertainty (of a measurement)
U
[3.16 of ISO 14253-1:1998 and 2.3.5 of GUM:1995]

NOTE U (capital) always indicates expanded uncertainty of measurement.

3.7
true uncertainty
U_A
uncertainty of measurement that would be obtained by a perfect uncertainty estimation

NOTE 1 True uncertainties are by nature indeterminate.

NOTE 2 See also 8.8.

3.8
conventional true uncertainty — GUM uncertainty
U_c
uncertainty of measurement estimated completely according to the more elaborate procedures of GUM

NOTE 1 The conventional true uncertainty of measurement may differ from an uncertainty of measurement estimated according to this Technical Specification.

NOTE 2 See also 8.8.

3.9
approximated uncertainty
U_{EN}
uncertainty of measurement estimated by the simplified, iterative method

NOTE 1 The index N indicates that U_{EN} is assessed by iteration number N. The designation U_E may be used without indication of the iteration number, when it is without importance to know the number of iterations.

NOTE 2 See also 8.8.

3.10
target uncertainty (for a measurement or calibration)
U_T
uncertainty determined as the optimum for the measuring task

NOTE 1 Target uncertainty is the result of a management decision involving e.g. design, manufacturing, quality assurance, service, marketing, sales and distribution.

NOTE 2 Target uncertainty is determined (optimized) taking into account the specification [tolerance or maximum permissible error (MPE)], the process capability, cost, criticality and the requirements of 4.11.1, 4.11.2 of ISO 9001:1994, 13.1 of ISO 9004-1:1994 and ISO 14253-1.

NOTE 3 See also 8.8.

3.11
required uncertainty of measurement
U_R
uncertainty required for a given measurement process and task

NOTE See also 6.2. The required uncertainty may be specified by, for example, a customer.

3.12
uncertainty management
process of deriving an adequate measurement procedure from the measuring task and the target uncertainty by using uncertainty budgeting techniques

3.13
uncertainty budget (for a measurement or calibration)
statement summarizing the estimation of the uncertainty components that contributes to the uncertainty of a result of a measurement

NOTE 1 The uncertainty of the result of the measurement is unambiguous only when the measurement procedure (including the measurement object, measurand, measurement method and conditions) is defined.

NOTE 2 The term "budget" is used for the assignment of numerical values to the uncertainty components, their combination and expansion, based on the measurement procedure, measurement conditions and assumptions.

3.14
uncertainty contributor
xx
source of uncertainty of measurement for a measuring process

3.15
limit value (variation limit) for an uncertainty contributor
a_{xx}
absolute value of the extreme value(s) of the uncertainty contributor, xx

3.16
uncertainty component
u_{xx}
standard uncertainty of the uncertainty contributor, xx

NOTE The iteration method uses the designation u_{xx} for all uncertainty components. This is not consistent with the present version of GUM which sometimes uses the designation s_{xx} for uncertainty components evaluated by A evaluation and the designation u_{xx} for uncertainty components evaluated by B evaluation.

3.17
influence quantity of a measurement instrument
characteristic of a measuring instrument that affects the result of a measurement performed by the instrument

3.18
influence quantity of a workpiece
characteristic of a workpiece that affects the result of a measurement performed on that workpiece

4 Symbols

For the purposes of this Technical Specification, the generic symbols given in Table 1 apply.

Table 1 — Generic symbols

Symbol	Description
a	limit value for a distribution
a_{xx}	limit value for an error or uncertainty contributor (in the unit of the result of measurement, of the measurand)
$a*_{xx}$	limit value for an error or uncertainty contributor (in the unit of the influence quantity)
α	linear coefficient of thermal expansion
b	coefficient for transformation of a_{xx} to u_{xx}
C	correction (value)
d	resolution of a measurement equipment
E	Young's modulus
ER	error (value of a measurement)
G	function of several measurement values [$G(X_1, X_2, ... X_i, ...)$]
h	hysteresis value
k	coverage factor
m	number of standard deviations in the half of a confidence interval
MR	measurement result (value)
n	number of ...
N	number of iterations
ν	Poisson's number
p	number of total uncorrelated uncertainty contributors
r	number of total correlated uncertainty contributors
ρ	correlation coefficient
TV	true value of a measurement
u, u_i	standard uncertainty (standard deviation)
s_x	standard deviation of a sample
$s_{\bar{x}}$	standard deviation of a mean value of a sample
u_{c}	combined standard uncertainty
u_{xx}	standard deviation of uncertainty contributor xx — uncertainty component
U	expanded uncertainty of measurement
U_{A}	true uncertainty of measurement
U_{C}	conventional true uncertainty of measurement
U_{E}	approximated uncertainty of measurement (number of iteration not stated)
$U_{\text{E}N}$	approximated uncertainty of measurement of iteration number N
U_{R}	required uncertainty
U_{T}	target uncertainty
U_{V}	uncertainty value (not estimated according to GUM or this Technical Specification)
X	measurement result (uncorrected)
X_i	measurement result (in the transparent box model of uncertainty estimation)
Y	measurement result (corrected)

5 Concept of the iterative GUM-method for estimation of uncertainty of measurement

Applying the GUM method completely one will find a conventional true uncertainty of measurement, U_C.

The simplified, iterative method/procedure of this Technical Specification is to achieve estimated uncertainties of measurements, U_E by overestimating the influencing uncertainty components/contributors ($U_E \geqslant U_C$). The process of overestimating provides "worst-case-contributions" at the upper bound from each known or predictable uncertainty contributor, thus ensuring results of estimations "on the safe side", i.e. not underestimating the uncertainty of measurement. The simplified, iterative method of this Technical Specification is based on the following:

— all uncertainty contributors are identified;

— it is decided which of the possible corrections shall be made (see 8.4.6);

— the influence on the uncertainty of the result of measurement from each contributor is evaluated as a standard uncertainty u_{xx}, called the uncertainty component;

NOTE As a convention in the iterative method the influence of each contributor must be converted into the unit of the measurand — using relevant physical equations/formulae and sensibility coefficients.

— an iteration process, PUMA (see clause 6);

— the evaluation of each of the uncertainty components (standard uncertainties) u_{xx} can take place either by type A-evaluation or by type B-evaluation;

— type B-evaluation is preferred — if possible — in the first iteration in order to get a rough uncertainty estimate to establish an overview and to save cost;

— the total effect of all contributors (called the combined standard uncertainty) is calculated by the formula:

$$u_c = \sqrt{u_{x1}^2 + u_{x2}^2 + u_{x3}^2 + \ldots + u_{xn}^2} \quad (1)$$

— the formula (1) is only valid for a black box model of the uncertainty estimation and when the components u_{xx} are all uncorrelated (for more details and other formulas see 8.6 and 8.7);

— for simplification the only correlation coefficients between contributors considered are

$$\rho = 1, -1, 0 \quad (2)$$

if the uncertainty components are not known to be uncorrelated, full correlation is assumed, either $\rho = 1$ or -1. Correlated components are added arithmetically before put into the formula above (see 8.5 and 8.6);

— the expanded uncertainty U is calculated by the formula:

$$U = k \times u_c \quad (3)$$

where $k = 2$; k is the coverage factor (see also 8.8);

The simplified, iterative method normally will consist of at least two iterations of estimating the components of uncertainty.

a) The first very rough, quick and cheap iteration has the purpose of identifying the largest components of uncertainty (see Figure 1);

b) The following iterations — if any — only deal with making more accurate "upper bound" estimates of the largest components to lower the estimate of the uncertainty (u_c and U) to a possible acceptable magnitude.

The simplified and iterative method may be used for two purposes:

a) Management of the uncertainty of measurement for a result of a given measurement process (can be used for the results from a known measuring process or for comparison of two or more of such results) — see 6.2.

b) Uncertainty management for a measuring process. Development of an adequate measuring process i.e. $U_E \leqslant U_T$ — see 6.3.

6 Procedure for Uncertainty MAnagement — PUMA

6.1 General

The prerequisite for uncertainty budgeting and management is a clearly identified and defined measuring task; i.e. the measurand to be quantified (a GPS characteristic of a workpiece or a metrological characteristic of a GPS measuring equipment). The uncertainty of measurement is a measure of the quality of the measured value according to the definitions of a GPS characteristic of the workpiece or a metrological characteristic of the GPS measuring equipment given in GPS standards.

GPS standards define the "conventional true values" (see 1.20 of VIM:1993) of the characteristics to be measured by chains of standards and global standards (see ISO/TR 14638). GPS standards in many cases also define the ideal — or conventional true — principle of measurement (see 2.3 of VIM:1993), method of measurement (see 2.4 of VIM:1993), measurement procedure (see 2.5 of VIM:1003) and Standard "reference conditions" (see 5.7 of VIM:1993).

Deviations from the standardized conventional true values of the characteristics, etc. (the ideal operator) are contributing to the uncertainty of measurement.

6.2 Uncertainty management for a given measurement process

Management of the uncertainty of measurement for a given measuring task (box 1 of Figure 1) and for an existing measurement process is illustrated in Figure 1. The principle of measurement (box 3), measurement method (box 4), measurement procedure (box 5) and measurement conditions (box 6) are fixed and given or decided in this case, and cannot be changed. The only task is to evaluate the consequence on the uncertainty of measurement. A required U_R may be given or decided.

Using the iterative GUM method the first iteration is only for orientation, and to look for the dominant uncertainty contributors. The only thing to do — in the management process in this case — is to refine the estimation of the dominant contributors to come closer to a true estimate of the uncertainty components thus avoiding a too big overestimate — if necessary.

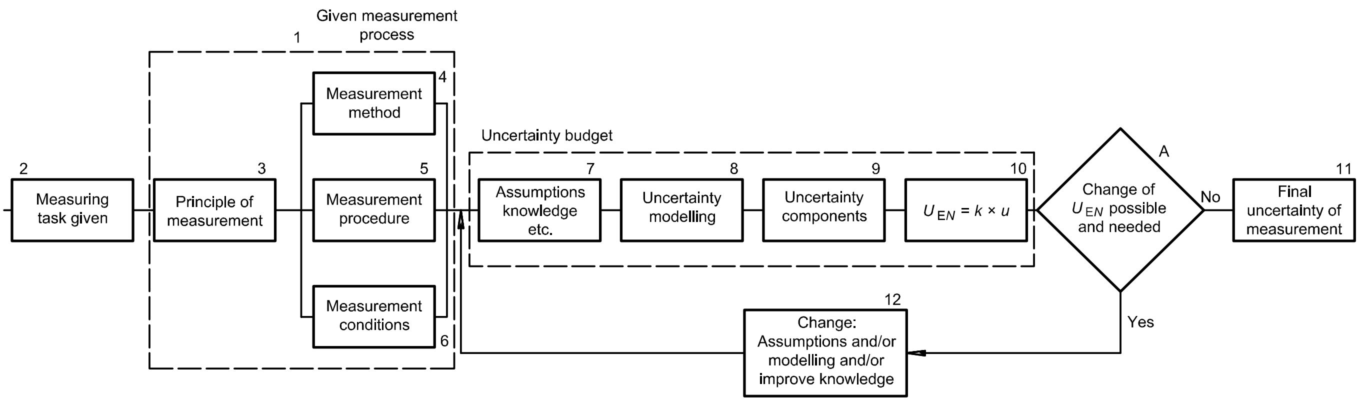

Figure 1 — Uncertainty management for a result of measurement from a given measurement process

The procedure is as follows:

a) make a first iteration based preferably on a black box model of the uncertainty estimation process and set up a preliminary uncertainty budget (boxes 7 to 9) leading to the first rough estimate of the expanded uncertainty, U_{E1} (box 10). For details about uncertainty estimation see 9. All estimates of uncertainties U_{EN} are performed as upper bound estimates;

b) compare the first estimated uncertainty, U_{E1}, with the required uncertainty U_R (box A) for the actual measuring task

   1) If U_{E1} is acceptable (i.e. if $U_{E1} \leqslant U_R$), then the uncertainty budget of the first iteration has proven that the given measurement procedure is adequate for the measuring task (box 11);

   2) If U_{E1} is not acceptable (i.e. if $U_{E1} > U_R$) or if there is no required uncertainty, but a lower and more true value is desired, the iteration process continues;

c) before the new iteration, analyze the relative magnitude of the uncertainty contributors. In many cases a few uncertainty components dominate the combined standard uncertainty and expanded uncertainty;

d) change the assumptions or improve the knowledge about the uncertainty components to make a more accurate (see 3.5 of VIM:1993) upper bound estimation of the largest (dominant) uncertainty components (box 12).

   Change to a more detailed model of the uncertainty estimation process or a higher resolution of the measuring process (box 12);

e) make the second iteration of the uncertainty budget (boxes 7 to 9) leading to the second, lower and more accurate (see 3.5 of VIM:1993) upper bound estimate of the uncertainty of measurement, U_{E2} (box 10);

f) compare the second estimated uncertainty U_{E2} (box A) with uncertainty required U_R for the actual measuring task

   1) if U_{E2} is acceptable (i.e. if $U_{E2} \leqslant U_R$), then the uncertainty budget of the second iteration has proven that the given measurement procedure is adequate to the measuring task (box 11);

   2) if U_{E2} is not acceptable (i.e. if $U_{E2} > U_R$), or if there is no required uncertainty, but a lower and more true value is desired, then a third (and possibly more) iteration(s) is (are) needed. Repeat the analysis of the uncertainty contributors [additional changes of assumptions, improve in knowledge, changes in modelling, etc. (box 12)] and concentrate on the currently largest uncertainty contributors;

g) when all possibilities have been used for making more accurate (lower) upper bound estimates of the measuring uncertainties without coming to an acceptable measuring uncertainty $U_{EN} \leqslant U_R$, then it is proven, that it is not possible to fulfil the given requirement U_R.

6.3 Uncertainty management for design and development of a measurement process/procedure

Uncertainty management in this case is performed to develop an adequate measurement procedure [measurement of the geometrical characteristics of a workpiece or the metrological characteristics of a measuring equipment (calibration)]. Uncertainty management is performed on the basis of a defined measuring task (box 1 in Figure 2) and a given target uncertainty, U_T (box 2 in Figure 2). Definition of the measuring task and target uncertainty are company policy decisions to be made at a sufficiently high management level. An adequate measurement procedure is a procedure which results in an estimated uncertainty of measurement less than or equal to the target uncertainty. If the estimated uncertainty of measurement is much less than the target uncertainty, the measurement procedure may not be (economically) optimal for performing the measuring task (i.e. the measurement process is too costly).

