TECHNICAL SPECIFICATION

ISO/TS 15530-3

First edition
2004-03-01

Geometrical Product Specifications (GPS) — Coordinate measuring machines (CMM): Technique for determining the uncertainty of measurement —

Part 3:
Use of calibrated workpieces or standards

Spécification géométrique des produits (GPS) — Machines à mesurer tridimentionnelles (MMT): Technique pour la détermination de l'incertitude de mesure —

Partie 3: Utilisation de pièces étalonnées ou des normes

Reference number
ISO/TS 15530-3:2004(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

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 15530 was prepared by the Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification* and consists of the following parts under the general title *Geometrical Product Specification (GPS) — Coordinate measuring machines (CMM) — Techniques for determining the uncertainty of measurement*:

— *Part 1: Overview and general issues*

— *Part 2: Use of multiple measurement strategies*

— *Part 3: Use of calibrated workpieces or standards*

— *Part 4: Use of computer simulation*

— *Part 5: Use of expert judgement*

Introduction

This part of ISO 15530 is a Geometrical Product Specification (GPS) Technical Specification and is to be regarded as a general GPS document (see ISO/TR 14638). It influences chain link 6 of the chain of standards on size, distance, radius, angle, form, orientation, location, run-out and datums.

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

Coordinate measuring machines (CMMs) have become essential for the verification of geometry in industry. According to the ISO 9000 series of standards, in a quality management system the relevant measuring equipment is required to be calibrated against certified equipment having a known and valid relationship to internationally or nationally recognized standards in order to establish traceability. According to the *International Vocabulary of Basic and General Terms in Metrology* (VIM), a calibration comprises — besides the establishment of the relationship between the measured and the correct values of a quantity — the uncertainty evaluation in the final results (measurands) of the measurement task. However, uncertainty evaluation methods covering the errors arising in the innumerable measurement tasks a CMM can actually perform are often very complex. In these cases the risk of an unrealistic estimation of task-related uncertainty is likely to arise.

The aim of this part of ISO 15530 is to provide an experimental technique for simplifying the uncertainty evaluation of CMM-measurements. In this experimental approach measurements are carried out in the same way as actual measurements, but with calibrated workpieces or standards of similar dimension and geometry instead of the unknown objects to be measured. The description of this experimental technique to evaluate measurement uncertainty is the key element of this part of ISO 15530. The standardization of such procedures for the uncertainty evaluation serves the world-wide mutual recognition of calibrations and other measurement results.

This part of ISO 15530 is applicable for non-substitution measurement of workpieces or standards, where the measurement result is given by the indication of the CMM. Furthermore, this part of ISO 15530 is applicable for substitution measurement, where, in opposition to the non-substitution measurement, a check standard is used to correct for the systematic errors of the CMM. The latter will generally decrease the measurement uncertainty and is often used, especially in the field of gauge calibration.

This part of ISO 15530 describes one of several methods of uncertainty evaluation, which will be outlined in later ISO documents. Because of the experimental approach, it is simple to perform, and it provides realistic statements of measurement uncertainties.

The limitations of this method can be summarised as: the availability of artefacts with sufficiently defined geometrical characteristics, stability, reasonable costs, and the possibility of being calibrated with sufficiently small uncertainty.

Geometrical Product Specifications (GPS) — Coordinate measuring machines (CMM): Technique for determining the uncertainty of measurement —

Part 3:
Use of calibrated workpieces or standards

1 Scope

This part of ISO 15530 specifies the evaluation of measurement uncertainty for results of measurements obtained by a CMM and by using calibrated workpieces. It provides an experimental technique for simplifying the uncertainty evaluation of CMM measurements, whose approach (substitution measurements) leads to measurements being carried out in the same way as actual measurements, but with calibrated workpieces of similar dimension and geometry instead of the unknown workpieces to be measured.

Non-substitution measurements on CMMs are also covered, as are the requirements of the uncertainty evaluation procedure, the measurement equipment needed, and the reverification and the interim check of the measurement uncertainty.

NOTE The evaluation of measurement uncertainty is always related to a specific measuring task.

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

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

Guide to the expression of uncertainty in measurement (GUM). BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1st edition, 1993, corrected and reprinted in 1995

3 Terms and definitions

For the purpose of this part of ISO 15530, the terms and definitions given in ISO 10360-1, VIM and GUM, and the following apply

3.1
non-substitution measurement
measurement where the uncorrected indication of the CMM is used as a result

3.2
substitution measurement
measuring procedure where both a workpiece and a check standard are measured in order to provide additional corrections for systematic errors of the CMM

4 Symbols

For the purpose of this part of ISO 15530, the symbols given in Table 1 apply.

Table 1 — Symbols

Symbol	Interpretation
b	Systematic error observed during the evaluation of the measurement uncertainty
Δ_i	Difference between the measured and calibrated values of the check standard when applying the substitution method
k	Coverage factor
l	Measured dimension
n	Number of repeated measurements
T	Average temperature of the workpiece or standard
u_{cal}	Standard uncertainty of the parameter of the calibrated workpiece or standard
u_{p}	Standard uncertainty of the measurement procedure
u_{w}	Standard uncertainty resulting from the influences of the workpiece or standard
u_{α}	Standard uncertainty of the expansion coefficient of the workpiece or standard
U	Expanded measurement uncertainty
U_{cal}	Expanded uncertainty of the calibrated workpiece parameter
x_{cal}	Value of the parameter of the calibrated workpiece or standard
y	Measurement result
y_i	Measurement results during evaluation of measurement uncertainty
y_i^*	Uncorrected indications of the CMM during evaluation of measurement uncertainty when applying the substitution method
$\bar{y}$	Mean value of the measurement result

5 Requirements

5.1 Operating conditions

Before starting the measurements, the CMM shall be initialized and procedures like probe configuration and probe qualification shall be performed according to the conditions specified in the manufacturer's operating manual. In particular, an adequate thermal equilibrium of the (calibrated) workpiece or standard and the CMM should exist.

For the measurements given in 7.2, the environmental and operational conditions quoted by the CMM manufacturer and conditions quoted in the user's quality manual shall apply. In particular, existing error compensating functions (like corrections applied via the software of the CMM's computer) shall be active if this is prescribed in the quality manual.

The CMM shall fulfil the specifications of the manufacturer, or — if different — the specifications laid down in the procedural instructions for the measurement task (task-related calibration, see ISO 14978), therefore, it is not necessary to calibrate all the metrological characteristics of a CMM (global calibration, see ISO 14978).

5.2 Similarity conditions

The method requires similarity of the following.

a) The dimension and geometry of the workpiece or standard used in the actual measurements (see 7.2.1) and the calibrated workpiece or standard used in the evaluation of measurement uncertainty (see 7.2.2).

NOTE Conditions to be reflected are, for example, positions and orientations.

b) The measurement procedure of the evaluation of measurement uncertainty and the actual measurement.

NOTE Conditions to be reflected are, for example, handling, exchange and clamping, time elapsed between probing points, loading and unloading procedures, measuring force and speed.

c) The environmental conditions (including all variations) during evaluation of measurement uncertainty and actual measurement.

NOTE Conditions to be reflected are, for example, temperature, temperature stabilisation time and temperature corrections (if used).

In Table 2, the similarity requirements are given.

Table 2 — Similarity requirements for workpieces or standard to be measured and the calibrated workpieces or standard used during evaluation of measurement uncertainty

<table>
<tr><th>Subject</th><th colspan="2">Requirements</th></tr>
<tr><td rowspan="2">Dimensional characteristics</td><td>Dimensions</td><td>Identical within:
— 10 % beyond 250 mm
— 25 mm below 250 mm</td></tr>
<tr><td>Angles</td><td>Identical within ± 5°</td></tr>
<tr><td>Form deviations and surface texture</td><td colspan="2">Similar due to functional properties</td></tr>
<tr><td>Material (e.g. thermal expansion, elasticity, hardness)</td><td colspan="2">Similar due to functional properties</td></tr>
<tr><td>Measuring strategy</td><td colspan="2">Identical</td></tr>
<tr><td>Probe configuration</td><td colspan="2">Identical</td></tr>
</table>

The similarity of the thermal conditions are considered to be assured if the above requirements are met. The evaluation of measurement uncertainty shall cover in particular the range of temperature which will prevail during the actual measurement. If the variation of the thermal expansion coefficient of the measured workpieces or standards is assumed as significant, this uncertainty contribution has to be taken into account (see 7.3.2).

For some CMMs, errors associated with dynamic effects may become significant with decreasing probe approach distance. For small internal features, e.g. a hole, the probe approach distance may be limited by the feature size. Consequently, care shall be taken to ensure that the probe approach distance is identical.

6 Principle of the uncertainty evaluation using calibrated workpieces

The evaluation of measurement uncertainty is a sequence of measurements, performed in the same way and under the same conditions as the actual measurements. The only difference is that instead of the workpieces to be measured, one or more calibrated workpieces are measured. The differences between the results obtained by the measurement and the known calibration values of these calibrated workpieces are used to estimate the uncertainty of the measurements.

The uncertainty of the measurement consists of uncertainty contributions:

a) due to the measurement procedure;

b) from the calibration of the calibrated workpiece;

c) due to the variations of the measured workpieces (changing form deviations, expansion coefficient and surface texture).

The full effect of all variation in environmental conditions should be included, to perform a comprehensive evaluation of the measurement uncertainty.

7 Procedure

7.1 Measuring equipment

The uncertainty evaluation on a CMM using calibrated workpieces requires the following equipment:

a) a task-related stylus set-up;

b) at least one calibrated workpiece.

The metrological characteristics of the calibrated workpieces shall be calibrated with a known and sufficiently low uncertainty to fulfil the requirements of the measurement task.

NOTE The uncertainty stated for the calibration of the calibrated workpieces should be valid for the measurement strategy employed during the actual measurements and the uncertainty evaluation.

7.2 Execution

7.2.1 General

The user of the CMM has a high degree of freedom to design the measurement procedure (i.e. the measurement strategy) according to the technical requirements. This is possible, because the procedure and conditions of actual measurements and those during the uncertainty evaluation shall be the same.

7.2.2 Actual measurement

One cycle of an actual measurement consists of the handling of the workpieces and one or more measurements of the workpieces (see Figure 1).

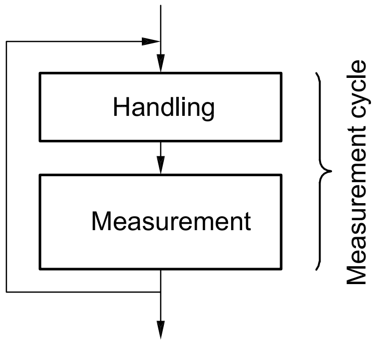

Figure 1 — Procedure of non-substitution measurement — Measuring cycle

The position and the orientation of the measured workpieces are free within the range covered by the uncertainty evaluation.

7.2.3 Uncertainty evaluation

The uncertainty evaluation shall be as follows.

Calibrated workpieces are measured instead of the workpieces. Calibrated workpieces and workpieces shall fulfill the similarity conditions outlined in 5.2. Special loading and unloading procedures shall be performed during the uncertainty evaluation.

To obtain a sufficient number of samples for the uncertainty evaluation, at least 10 measurement cycles and a total of at least 20 measurements on calibrated workpieces shall be carried out. This implies, e.g. a total of 20 cycles min., if only one calibrated workpiece per cycle is measured.

During the uncertainty evaluation, the position and orientation of the calibrated workpieces are systematically varied within the limits given by the procedure of the actual measurements.

As specified in 7.2.1, a measuring cycle shall contain all actions involved in a real measurement to assure the similarity of thermal conditions. This implies, e.g. that the CMM has to move through the same positions as if a complete measurement were being carried out, even though during the uncertainty evaluation not all workpieces may be present (dummy measurements).

7.3 Calculation of the uncertainty

7.3.1 General

In a calibration certificate or measurement report the measurement result, y, and its expanded uncertainty, U, shall be expressed in the form $y \pm U$, where U is determined with a coverage factor $k = 2$ for an approximated coverage probability of 95 %.

When performing the measurements, basically three uncertainty contributions shall be taken into account, described by the following standard uncertainties:

u_{cal} standard uncertainty resulting from the uncertainty of the calibration of the calibrated workpiece stated in the calibration certificate;

u_{p} standard uncertainty resulting from the measurement procedure as assessed in the uncertainty evaluation described below;

u_{w} standard uncertainty resulting from material and manufacturing variations (due to the variation of expansion coefficient, form errors, roughness, elasticity and plasticity).

In addition, a systematic error, b, may be considered separately.

The expanded measuring uncertainty, U, of any measured parameter is calculated from these standard uncertainties as:

$$U = k \times \sqrt{u_{\text{cal}}^2 + u_p^2 + u_w^2} + |b|$$

The coverage factor, k, is recommended to be chosen as k = 2 for a coverage probability of 95 %.

In Table 3, the uncertainty contributions for the measurement are listed.

Table 3 — The uncertainty components and their consideration in the uncertainty assessment

Uncertainty component	Method of evaluation (according to GUM)	Designation
Geometrical errors of CMM	A	assessed in a sum u_P
Temperature of CMM		
Drift of CMM		
Temperature of workpiece		
Systematic errors of probing system		
Repeatability of the CMM		
Scale resolution of the CMM		
Temperature gradients of the CMM		
Random errors of the probing system		
Probe changing uncertainty		
Errors induced by the procedure (clamping, handling, etc.)		
Errors induced by dirt		
Errors induced by the measuring strategy		
Calibration of the calibrated workpiece	B	u_{cal}
Variations among workpieces and calibrated workpiece in — roughness — form — expansion coefficient — elasticity	A or B	u_W
NOTE The list of uncertainty contributors may not be exhaustive.		

The individual standard uncertainties are evaluated as follows.

7.3.2 Standard uncertainty u_{cal} of the calibrated workpiece

The standard uncertainty, U_{cal}, is evaluated from the expanded measuring uncertainty, U_{cal}, and the coverage factor, k, given in the calibration certificate:

$$u_{\text{cal}} = \frac{U_{\text{cal}}}{k}$$

Careful attention should be given to 3.3.2 in GUM to be certain that the calibration uncertainty represents the same measurand as used in the measurement. If this is not the case, additional terms of uncertainty have to be considered.

7.3.3 Uncertainty due to the measurement process

7.3.3.1 Standard uncertainty u_p

The standard uncertainty, u_p, is determined by

$$u_\text{p} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

with

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

and n the number of measurements.

7.3.3.2 Systematic error, b

In most cases a systematic deviation, b, between the indicated value of the CMM, y_i, and the calibrated value of the calibrated workpiece, x_cal, may be observed:

$$b = \bar{y} - x_\text{cal}$$

If this systematic error is not corrected due to economical or practical reasons, it has to be added to the expanded uncertainty as shown in 7.3.1.

NOTE This treatment of a non-corrected systematic error is in conformance with GUM (especially chapter 6.3.1 and appendix F.2.4.5).

If due to a large systematic error a correction is applied or it is decided to apply the substitution method (see 7.4) to minimize the systematic error, the uncertainty evaluation according to 7.2.2 has to be repeated.

7.3.4 Standard uncertainty u_w from the manufacturing process

Variation of form errors and roughness due to the changing manufacturing process as well as variation of expansion coefficient and elasticity due to changing material and surface properties of the workpieces to be measured influence the uncertainty of a measurement. The standard uncertainty, u_w, covers these influences. If the calibrated workpiece used and all measured workpieces correspond in the above-mentioned properties within the required uncertainty limits, this contribution may be classified as insignificant and therefore can be neglected. Note that, using a calibrated workpiece, the above-mentioned uncertainty contributions are partly considered. If the uncertainty contributions of the manufacturing process cannot be neglected, additional terms have to be considered. The respective tolerances in form and roughness may serve to assess these contributions. In particular a significant uncertainty contribution results from the variation of the expansion coefficient of the measured workpieces. In this case the uncertainty, u_w, is calculated by:

$$u_\text{w} = (T - 20\,°\text{C}) \times u_\alpha \times l$$

where

u_α is the standard uncertainty of the expansion coefficient of the workpieces;

T is the average temperature of the workpiece during the measurement procedure;

l is the measured dimension.

The standard uncertainty, u_α, can be evaluated from the range of the expansion coefficient which may be delivered by the material supplier.

It shall be assured that the expansion coefficient of the calibrated workpiece used lies within the stated range of the expansion coefficients for the measured workpieces.

7.4 Applying the substitution method: special considerations

In some cases, e.g. in gauge calibration, the influence of systematic errors of the CMM may be corrected. For this purpose the measurement of an additional calibrated working standard is included in the measuring cycle (see Figure 2). By measuring this working standard regularly and comparing the calibrated value of the working standard with the indication of the CMM, a correction value, Δ_i, is derived, which then is applied for the measurement of the workpieces. This procedure is called the substitution method.

The proposed method to assess measurement uncertainty outlined in this standard is also applicable for the substitution method, but some special considerations have to be taken into account.

— The measurement results, y_i, of the uncertainty evaluation (see 7.3.3.1) have to take into account the corrections Δ_i which are applied to the indicated values of the CMM, y_i^* as follows:

$$y_i = y_i^* + \Delta_i$$

— The uncertainty shall cover the whole measurement procedure. Therefore, the measurement of the working standard and any additional handling shall be included in the uncertainty evaluation.

— The working standard is an intrinsic part of the measurement procedure. Its calibration uncertainty is considered in the experimental procedure. No additional uncertainty contribution need be added.

— The working standard shall not be used as a calibrated workpiece during the uncertainty evaluation. It is necessary to clearly distinguish between the working standard for correction and the calibrated workpiece to analyze the measurement process.

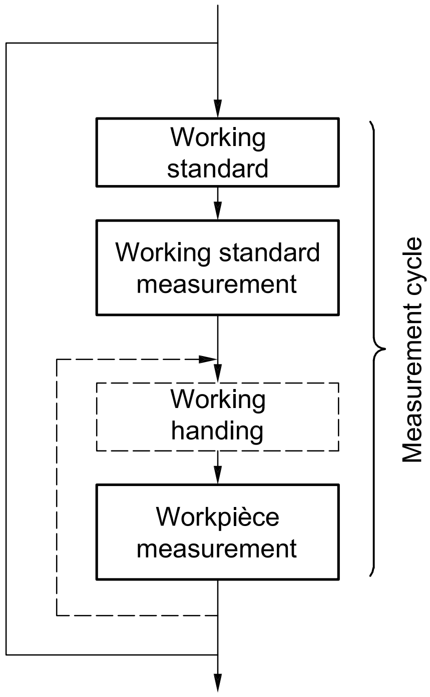

Figure 2 — Procedure of substitution measurement — Measuring cycle

8 Reverification of the measurement uncertainty

The uncertainty evaluation as specified in 7.2.2 should be repeated regularly.

9 Interim check of the measurement uncertainty

The interim check is a simplification of the uncertainty evaluation (see 7.2.2) where calibrated workpieces are substituted in a statistical sampling manner, for the workpieces to be measured. It serves to check whether any assumptions made regarding long period variations in the measuring conditions, in particular the temperature, are still valid. The time intervals between interim checks are specified by the user of the CMM. They are dependent on the required measuring uncertainty and on the environmental conditions.

In an interim check, calibrated workpieces are substituted for the workpieces to be measured in a sampling manner. The deviation between the calibration value for the workpieces and the corresponding measured value from such an interim check shall be smaller than the stated expanded uncertainty, U. If this is not the case, and the reason for this deterioration of the uncertainty cannot be found and remedied, a reverification shall be made.

NOTE Sampling manner means and ensures that over time all positions, orientations and dimensions of the workpieces to be measured will have been checked.

Annex A
(informative)

Examples of application

A.1 Example 1: Measurement of a pump housing

A.1.1 Scenario

For quality assurance, a CMM is integrated in the production line for pump housings. To assure the quality of the part and to fulfill the requirements of the quality system, the task-specific uncertainties of the most critical measurements performed in the production line have to be known and have to be in an acceptable ratio to the respective tolerance of the part. Figure A.1 shows a simplified drawing of the pump housing.

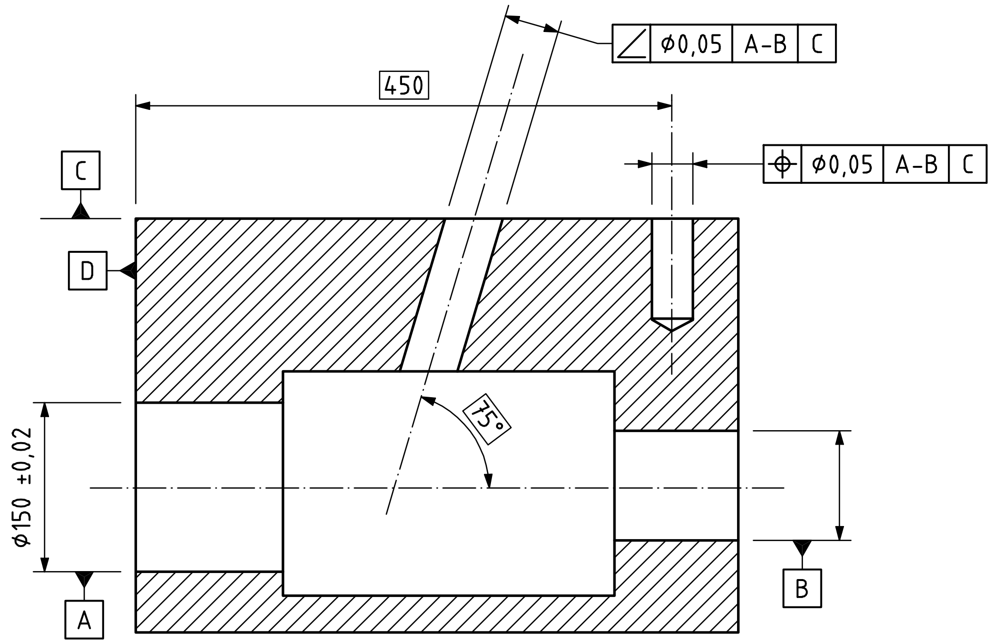

Figure A.1 — Technical drawing of the pump housing (simplified)

A.1.2 Procedure for experimental uncertainty evaluation

The procedure is as follows.

— **Step1**

One workpiece out of the production series is calibrated with a high precision CMM in a laboratory environment. This can be done, for example, by a service provider, who is capable of stating a valid uncertainty for each measured parameter. The traceabilty of this calibration shall be documented.

The measurement strategy shall reflect as closely as possible the GPS definition of the feature specified in the drawing. In general, this implies a relatively large number of probing points. The result is a calibrated workpiece, where all parameters x_i have stated uncertainties $U_{\text{cal}}(x_i)$.

The calibration certificate for the workpiece is as given in Table A.1.

Table A.1

Parameter	Measurement of: diameter mm	angularity mm	position mm	...
x_i	150,001 5	0,019 6	0,013 8	...
$U_{cal}(x_i)$	0,002 0	0,004 0	0,003 0	...

— **Step 2**

The calibrated workpiece is then measured on the CMM in the production line using the measurement strategy suitable for measurement in production, in general, a reduced number of probing points, for economic reasons.

This measurement is repeated at least 20 times under different conditions (different shifts, different thermal conditions, etc.) in accordance with 5.2. These measurements should ideally be also spread over a longer time period.

The results are collected and evaluated according to the formulae stated in 7.3. Table A.2 shows the results of the experimental uncertainty assessment.

Table A.2 — Results of the experimental uncertainty assessment

No.	Date/Time	Operator	Measurement of: diameter mm	angularity mm	position mm	...
1	2003-03-22, 07:33 am	A	150,003 7	0,013 4	0,014 4	...
2	2003-03-22, 08:23 am	A	150,004 3	0,016 4	0,013 4	...
3	2003-03-22, 10:02 am	A	150,003 0	0,017 4	0,014 4	...
4	2003-03-22, 01:55 pm	B	150,002 1	0,020 0	0,013 3	...
5	2003-03-22, 02:13 pm	B	150,003 3	0,018 3	0,015 3	...
6	2003-03-27, 06:08 am	B	150,003 9	0,017 2	0,014 2	...
7	2003-03-27, 07:11 am	B	150,003 2	0,017 4	0,014 4	...
8	2003-03-27, 02:13 pm	A	150,002 7	0,017 4	0,013 4	...
9	2003-03-27, 02:44 pm	A	150,002 5	0,016 9	0,013 9	...
10	2003-03-27, 05:14 pm	A	150,003 2	0,019 3	0,013 3	...
11	2003-03-28, 07:13 am	C	150,002 1	0,016 6	0,014 6	...
12	2003-03-28, 09:02 am	C	150,002 4	0,016 4	0,014 4	...
13	2003-03-28, 09:12 am	C	150,002 4	0,016 3	0,014 3	...
14	2003-03-28, 10:02 am	C	150,003 0	0,017 5	0,014 5	...
15	2003-03-28, 11:32 am	B	150,003 1	0,019 8	0,013 8	...
16	2003-03-28, 02:13 pm	B	150,003 4	0,019 6	0,013 6	...
17	2003-03-28, 03:13 pm	B	150,002 2	0,019 3	0,013 3	...
18	2003-03-28, 03:40 pm	B	150,002 0	0,019 0	0,012 9	...
19	2003-03-28, 04:20 pm	B	150,001 8	0,018 8	0,012 8	...
20	2003-03-28, 06:11 pm	A	150,003 0	0,018 3	0,012 9	...
Calibration uncertainty U_{cal} (see 7.3.2)			0,002 0	0,004 0	0,003 0	...
Standard calibration uncertainty u_{cal} (see 7.3.2)			0,001 0	0,002 0	0,001 5	...
Uncertainty procedure up (see 7.3.3.1)			0,000 8	0,001 6	0,000 7	...
Calibrated value x_{cal} (see 7.3.3.2)			150,001 5	0,019 6	0,013 8	...
Mean value $\overline{y}$ (see 7.3.3.2)			150,002 7	0,017 8	0,013 9	...
Systematic deviation $\lvert b \rvert$ (see 7.3.3.2)			0,001 2	0,001 8	0,000 1	...

— **Step 3**

Finally, the uncertainty contributor u_W has to be estimated (see Table A.3). In this example, the calibrated workpiece is deemed representative for the whole production lot concerning form and surface properties. Therefore, only the possible variation of the expansion coefficient is considered separately.

Table A.3

Workpiece uncertainty contributor	Measurement of: diameter mm	angularity mm	position mm	...
Production variation	insignificant	insignificant	insignificant	...
Uncertainty expansion coefficient (see 7.3.4)	0,000 2	0,000 5	0	...
u_W	0,000 2	0,000 5	0	...

A.1.3 Resulting uncertainty

The resulting expanded uncertainty is calculated from the formula stated in 7.3.1. It results in the following measurement uncertainties for each parameter (see Table A.4).

Table A.4

Contributor	Measurement of: diameter mm	angularity mm	position mm	...
u_{cal}	0,001 0	0,002 0	0,001 5	...
u_p	0,000 8	0,001 6	0,000 7	...
u_W	0,000 2	0,000 5	0	...
$\lvert b \rvert$	0,001 2	0,001 8	0,0001	...
U (k = 2)	0,004	0,007	0,003	...

These expanded uncertainties are assigned to each corresponding parameter of all workpieces measured. They can, for example, be used for conformance decisions based on ISO 14253-1.

A.1.4 Interim check

Once every week the calibrated workpiece is substituted for a workpiece to be measured. To validate the stated measurement uncertainty, the calibrated value of the calibrated workpiece is compared with the measured value. The difference must not exceed the expanded uncertainty U.

A.2 Example 2: Calibration of ring gauges on a laboratory CMM

A.2.1 Scenario

A calibration laboratory of an automotive company calibrates ring gauges of very similar size in large quantities on a CMM for internal purposes. To reduce systematic errors of the CMM, a calibrated working standard is used in a substitution process (see 7.4): the working standard is stationary clamped on the CMM, while the gauges to be measured are clamped on an exchangeable pallet. During the procedure, the CMM measures the working standard before and after the measurement of the pallet of ring gauges to be calibrated. The calibrated value of the working standard minus the average of the two observed values of the working standard is added as a correction to the observed value of each gauge on the pallet.

A.2.2 Procedure for experimental uncertainty evaluation

The procedure is as follows.

— **Step 1**

One additional ring gauge is independently calibrated in an accredited laboratory outside the company. This ring gauge is defined as the “calibrated workpiece”.

— **Step 2**

After the measurement routines on the CMM have been fully established, one of the regular ring gauges to be calibrated is now replaced by the calibrated workpiece and the whole measurement process (including the substitution measurements on the working standard) is performed 20 times under varying conditions (see 5.2). Each time, a different gauge on the pallet is replaced by the calibrated workpiece.

The correction value determined by the measurements of the working standard is applied to the results of the calibrated workpiece in the same manner as for all other ring gauges.

The results are collected and evaluated according to the formulae specified in 7.3. Table A.5 shows the results.

Table A.5 — Results of the experimental uncertainty assessment

No.	Date / Time	Operator	y_i^*	Δ_i	y_i
1	2003-04-22, 07:33 am	A	50,000 3	0,0011	50,001 4
2	2003-04-22, 08:23 am	A	50,000 5	0,0013	50,001 8
3	2003-04-22, 10:02 am	A	49,999 8	0,0015	50,001 3
4	2003-04-22, 01:55 pm	A	49,999 8	0,0019	50,001 7
5	2003-04-22, 02:13 pm	A	49,999 9	0,001 4	50,001 3
6	2003-04-27, 06:08 am	B	50,000 3	0,001 2	50,001 5
7	2003-04-27, 07:11 am	B	50,001 3	0,000 4	50,001 7
8	2003-04-27, 02:13 pm	A	50,001 1	0,000 6	50,001 7
9	2003-04-27, 02:44 pm	A	50,000 3	0,000 9	50,001 2
10	2003-04-27, 05:14 pm	A	50,000 3	0,001 2	50,001 5
11	2003-04-28, 07:13 am	B	50,000 5	0,001 3	50,001 8
12	2003-04-28, 09:02 am	B	50,000 3	0,001 4	50,001 7
13	2003-04-28, 09:12 am	A	49,999 5	0,001 8	50,001 3
14	2003-04-28, 10:02 am	A	50,000 3	0,001 4	50,001 7
15	2003-04-28, 11:32 am	B	50,000 3	0,001 5	50,001 8
16	2003-04-28, 02:13 pm	B	50,000 7	0,001 5	50,002 2
17	2003-04-28, 03:13 pm	B	50,000 8	0,001 3	50,002 1
18	2003-04-28, 03:40 pm	B	50,0003	0,001 1	50,001 4
19	2003-04-28, 04:20 pm	B	50,0011	0,000 2	50,001 3
20	2003-04-28, 06:11 pm	A	50,0013	0,000 4	50,001 7
Calibration uncertainty U_{cal} (see 7.3.2)					0,000 4
Standard calibration uncertainty u_{cal} (see 7.3.2)					0,000 2
Uncertainty procedure u_p (see 7.3.3.1)					0,000 3
Calibrated value x_{cal} (see 7.3.3.2)					50,001 7
Mean value $\overline{y}$ (see 7.3.3.2)					50,001 6
Systematic deviation $\lvert b \rvert$ (see 7.3.3.2)					0,000 1

— **Step 3**

The calibrated workpiece is a new ring gauge which has not been used in production, while many of the ring gauges to be calibrated on the CMM show some wear marks on the surface. Tests have shown that the reproducibility of the measurement on the used ring gauges is worse than for the new ones. From the test data, an additional uncertainty contributor, u_W = 0,000 2 mm, is estimated. The laboratory is temperature controlled to within ± 0,5 K. Therefore, the contribution due to uncertainty of the expansion coefficient has been found to be insignificant.

A.2.3 Resulting uncertainty

The resulting expanded uncertainty is calculated from the formula stated in 7.3.1. It results in an expanded uncertainty U = 0,000 9 mm (k = 2). This uncertainty is assigned to each ring gauge of a nominal diameter between 25 mm and 75 mm calibrated on this CMM (see similarity conditions in 5.2).

A.2.4 Interim check

When ring gauges are calibrated on the CMM, the calibrated workpiece is substituted regularly for one workpiece to be measured. To validate the stated measurement uncertainty, the calibrated value of the calibrated workpiece is compared with the measured value. The difference must not exceed the expanded uncertainty U.

Annex B
(informative)

Relation to the GPS matrix model

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

B.1 Information about the standard and its use

This part of ISO 15530 specifies evaluation of measurement uncertainty for results of measurements obtained by a CMM and by using calibrated workpieces.

B.2 Position in the GPS matrix model

This part of ISO 15530 is a general GPS document which influences chain link 6 of the chain of standards on size, distance, radius, angle, form, orientation, location, run-out and datums in the general GPS matrix as graphically illustrated in Figure B.1.

Fundamental GPS standards

Global GPS standards

General GPS standards						
Chain link number	1	2	3	4	5	6
Size						
Distance						
Radius						
Angle						
Form of line independent of datum						
Form of line dependent on datum						
Form of surface independent of datum						
Form of surface dependent on datum						
Orientation						
Location						
Circular run-out						
Total run-out						
Datums						
Roughness profile						
Waviness profile						
Primary profile						
Surface imperfections						
Edges						

Figure B.1

B.3 Related standards

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

Bibliography

[1] ISO/TR 14638:1995, *Geometrical Product Specifications (GPS) — Masterplan*

[2] ISO 14978:—[1)], *Geometrical Product Specifications (GPS) — General concepts and requirements for GPS measurement equipment*

1) To be published.

ICS 17.040.30

Price based on 16 pages