TECHNICAL SPECIFICATION

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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

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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order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn.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 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

Subject		Requirements
Dimensional characteristics	Dimensions	Identical within: — 10 % beyond 250 mm — 25 mm below 250 mm
	Angles	Identical within ± 5°
Form deviations and surface texture	Similar due to functional properties	
Material (e.g. thermal expansion, elasticity, hardness)	Similar due to functional properties	
Measuring strategy	Identical	
Probe configuration	Identical	

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).

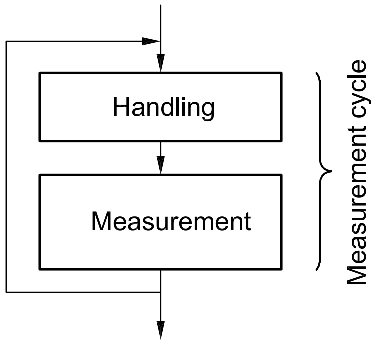

Figure 1 — Procedure of non-substitution measurement — Measuring cycle

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).

