TECHNICAL SPECIFICATION

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

Part 1: Overview and metrological characteristics

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

Partie 1: Vue d'ensemble et caractéristiques métrologiques

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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.

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. www.iso.org/directives

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

ISO 15530 consists of the following parts, under the general title *Geometrical product specifications (GPS) — Coordinate measuring machines (CMM): Technique for determining the uncertainty of measurement*:

— *Part 1: Overview and metrological characteristics* [Technical Specification]

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

— *Part 4: Evaluating task-specific measurement uncertainty using simulation* [Technical Specification]

Introduction

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.

The ISO/GPS masterplan given in ISO/TR 14638 gives an overview of the ISO/GPS system of which this document is a part. The fundamental rules of ISO/GPS given in ISO 8015 apply to this document and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this document, unless otherwise indicated.

For more detailed information on the relation of this part of ISO 15530 to other standards and the GPS matrix model, see Annex C.

It is the purpose of the ISO 15530 series to provide terminology, techniques and guidelines for estimating task-specific measurement uncertainty when using coordinate measuring machines (CMMs). These techniques allow for the evaluation of sources of uncertainty that affect a stated measurement, including the influence of the coordinate measuring system, the sampling strategy, environmental effects, operator variability and any other factors affecting the actual measurement result.

CMMs are considered to be complex GPS measuring equipment, and the estimation of the uncertainty of CMM measurements often involves more advanced techniques than those described in ISO 14253-2. The techniques presented in the ISO 15530 series are compliant with both ISO 14253-2 and ISO/IEC Guide 98-3 (GUM). The techniques are developed specifically for CMMs but could be applied to other GPS measuring equipment.

CMMs are specified by acceptance tests in the ISO 10360 series, which typically involve their ability to measure calibrated lengths (e.g. volumetric tests using calibrated gauge blocks or step gauges) and form (e.g. probing tests using a calibrated sphere). It is recognized that although these test results may be used to determine an uncertainty for the specific types of length and form measurements involved in these procedures, without further analysis or testing, these results are insufficient to determine the task-specific measurement uncertainty of most workpiece measurements.

The goal of determining the measurement uncertainty can be achieved through many different techniques; however, all methods must be consistent with ISO/IEC Guide 98-3, which yields a combined standard uncertainty. The expanded uncertainty is connected to the combined standard uncertainty via the coverage factor, which is selected to produce the desired level of confidence. The default value for the coverage factor is two, i.e. $k = 2$, which yields a level of confidence of approximately 95 % if the uncertainty is associated with a Gaussian distribution. It is the purpose of this document to provide guidance on recognized techniques for the estimation of uncertainty of CMM measurements.

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

Part 1: Overview and metrological characteristics

1 Scope

This part of ISO 15530 provides an overview of the ISO 15530 series. It discusses the metrological characteristics of coordinate measuring machines (CMMs), the sources of task-specific uncertainty, and the relationship between the ISO 10360 and ISO 15530 series.

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

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 14253-2:2011, *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*

ISO 14978:2006, *Geometrical product specifications (GPS) — General concepts and requirements for GPS measuring equipment*

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 purpose of this document, the terms and definitions given in ISO 10360-1, ISO 14253-1, ISO 14253-2, ISO 14978, ISO/IEC Guide 98-3, ISO/IEC Guide 99 and the following apply.

3.1
task-specific measurement uncertainty
expanded uncertainty using a coverage factor of two ($k = 2$), evaluated according to ISO/IEC Guide 98-3, of a specific measurement result

Note 1 to entry: Task-specific measurement uncertainty takes into account all uncertainty sources associated with the details of the measurement process, including the CMM, probing system, sampling strategy, workpiece location and orientation, fixturing, contamination, thermal environment.

1) To be published. (Revision of ISO 14253-1:1998)

Note 2 to entry: Different parameters of a feature, in general, have different uncertainties, e.g. the X and Y ordinates of the centre of a circle could have different uncertainties.

Note 3 to entry: Changing any influence quantity, e.g. the workpiece location in the CMM work zone, may change the task-specific measurement uncertainty.

3.2
sampling strategy
number and spatial distribution of probing points used to measure a geometric feature

4 Metrological characteristics

4.1 General

Metrological characteristics of CMMs are of interest for the control of errors and uncertainty contributors originating from the CMM and for the evaluation of uncertainty of measurement when using the CMM. The influence of the individual metrological characteristics on the uncertainty of measurement is dependent on the measurement process. The knowledge of the existence of the actual metrological characteristics and the magnitude of their values may be the basis for the design of the measurement process and the choice of the CMM.

4.2 Commerce

All metrological characteristics and their MPE (maximum permissible error) or MPL (maximum permissible limit) values apply to the defined operating conditions of the specific CMM, e.g. probe system qualification, speed of travel, etc. Operating conditions for CMMs are generally found in the manufacturer's operating manuals and specification data sheets and not normally in ISO standards. All metrological characteristics and their MPE or MPL values apply to all possible orientations in space, unless specific restrictions to the orientation are stated in the specific ISO standard or by the manufacturer.

MPE or MPL values or functions for metrological characteristics for acceptance tests shall be supplied by the manufacturer/supplier. The manufacturer may add additional information about metrological characteristics and their MPE or MPL values.

4.3 Internal use in an organization

The customer shall identify and understand the major metrological characteristics by means of uncertainty budgeting (for examples, see ISO 14253-2). Expert judgment and prior knowledge can be used in the uncertainty estimation procedure. Calibration procedures can also be chosen based on uncertainty budgets using expert judgment and prior knowledge.

MPE or MPL values or functions for metrological characteristics for internal calibrations and for reverification tests shall be supplied by the user.

4.4 Identification, definition, and choice of metrological characteristics

4.4.1 Choice of metrological characteristics

Metrological characteristics of the CMM may be chosen and defined in several ways. Metrological characteristics of the requirements (MPE and MPL) for these characteristics should preferably be chosen and defined, including the necessary conditions, with respect to:

— common intended use of the CMM;

— independence of other metrological characteristics;

— the use in control of uncertainty contributors that relate to the CMM;

— relevance to the physical principles inherent in the CMM;

— the use in maintenance activities and error identification;

— relation to specific parts or functions, or both, in the CMM;

— measuring principle;

— relevance of magnitude compared to other metrological characteristics.

It may be beneficial for a user of a CMM to define metrological characteristics other than those given in the standards to better fit the needs and intended use of the CMM.

4.4.2 Metrological characteristics in ISO 10360

The metrological characteristics defined in various parts of ISO 10360, as specified by the MPE or MPL values, could be considered in the choice of metrological characteristics for a CMM.

4.4.3 Machine geometry errors and residual error motion

The geometric error motions of the moving elements of a CMM, e.g. straightness, squareness, roll, pitch, and yaw, can often be measured. CMMs often utilize some type of software compensation for these geometric error motions; however, residual errors may exist and these errors could also be considered in the choice for metrological characteristics for a CMM.

4.4.4 Organization-specific requirements

Organizations may have specific or unique measurement requirements that can result in the selection of specific metrological characteristics to meet those requirements.

4.4.5 Other metrological characteristics

A list of possible metrological characteristics to consider for a CMM is included in Annex B. This list is not exhaustive, though it can be considered rather complete.

4.5 Calibration of metrological characteristics

The necessary metrological characteristics for the intended use of the CMM should be chosen and verified by calibration (or reverification tests.) The calibrated values of the metrological characteristics should be stated with the related measurement uncertainty, and, where appropriate, the calibrated values of the metrological characteristic should be proven to be in conformance with MPE values.

NOTE In the normal use of measuring instruments, it is often possible and proper to limit the number of requirements (different MPEs) and the extent of resources used to prove that the measuring instrument is functioning according to the setup requirements (MPLs and MPEs).

5 Task-specific uncertainty

5.1 General

Modern coordinate measurement systems, typically involving multi-axis CMMs, are affected by an extraordinary range of uncertainty sources. Thus, a complete assessment of the uncertainty sources and how they influence a specific measurement result can be a formidable task. For purposes of this part of ISO 15530, three general uncertainty categories are described that encompass not only the CMM itself but also the entire measurement process. An extensive list of potential uncertainty sources can be found in Annex B.

5.2 Instrumentation factors

Instrumentation factors include all errors that cause the measuring instrument, e.g. the CMM, to inaccurately measure points in space. This may be due to geometrical errors in the machine structure (both inherent to the manufacture of the CMM and those induced by dynamic effects, workpiece loading, and the environment, i.e. temperature, vibration, etc.), errors in the probing system, and errors in other sensor systems (temperature sensors, pressure sensors, etc.). Additionally, errors in the mathematical formulation and execution of associated-feature-fitting algorithms supplied by the manufacturer for data manipulation are included in this category. These factors are typically the responsibility of the CMM manufacturer and are controlled by establishing permissible limits, e.g. temperature ranges, under which the CMM may be used. Some or all of these error sources may be assessed during acceptance or reverification testing of the CMM.

5.3 Measurement plan factors

Measurement plan factors involve how the CMM user decides to execute the measurement. This includes the workpiece location and orientation, the probes and styli selected for the measurement, and the particular measurement point sampling strategy. Additionally, the quantity being measured, i.e. the measurand, shall be unambiguously specified. For example, in the case of a cylinder diameter measurement, the user shall decide if a least-squares, minimum-circumscribed, maximum-inscribed or minimum-zone result is desired. Some measurement plan factors may also influence the sensitivity coefficients of other uncertainty components, for example the magnitude of a probe offset amplifies CMM geometry errors.

5.4 Extrinsic factors

Extrinsic factors are often beyond the control of the CMM manufacturer and CMM user; nevertheless, they affect the task-specific measurement uncertainty. They include non-ideal workpiece geometry (such as surface roughness, form errors, finite stiffness and thermal distortions), contamination, workpiece fixturing problems and variations among operators.

6 Techniques to determine task-specific measurement uncertainty components

6.1 General issues

To evaluate task-specific measurement uncertainty, the instrumentation, measurement plan and extrinsic uncertainty sources shall be evaluated and combined in a manner consistent with ISO/IEC Guide 98-3. Typically, several different evaluation techniques may be needed to include all sources. The various uncertainty sources are then combined together using the law of propagation of uncertainty, yielding the combined standard uncertainty. The combined standard uncertainty is then multiplied by the coverage factor to yield the expanded uncertainty. The listing of the uncertainty sources, their combination, and expression of the expanded uncertainty is known as the uncertainty budget.

6.2 Sensitivity analysis

This technique is described in ISO/IEC Guide 98-3. ISO 14253-2 is a simplified and iterative implementation of this technique. Since CMMs are complex measuring instruments, directly implementing this technique may only be possible for a limited number of measuring tasks. Essentially, the technique consists of four steps.

a) List each uncertainty source to be included in the sensitivity analysis.

   NOTE There are many different ways to separate uncertainty sources; hence, two equally valid uncertainty budgets may have a different number of sources.

b) For each uncertainty source listed, quantify its magnitude by one standard deviation (known as the standard uncertainty of the source).

c) For each uncertainty source, determine its sensitivity coefficient and correlation with other uncertainty sources, i.e. determine its influence on the measurand.

d) Combine the product of each standard uncertainty and its sensitivity coefficient together with any correlated uncertainty effects using the law of propagation of uncertainty.

6.3 Use of calibrated workpieces or standards (ISO 15530-3)

The use of calibrated workpieces or standards is a very powerful method from the perspective of capturing the appropriate uncertainty sources and their interactions. This technique uses a calibrated master workpiece to evaluate the instrumentation, measurement plan and many of the extrinsic uncertainty sources. By examining repeated measurements on the calibrated workpiece, the technique evaluates most of the uncertainty sources. However, this technique requires the use of a calibrated workpiece, which is both expensive and reduces much of the versatility of the CMM. Additionally, some sources of uncertainty (particularly extrinsic factors) may need to be independently evaluated. In this case the uncertainty resulting from applying this technique is combined with others in an overall uncertainty budget. This technique is most easily applied for simple geometric features where calibrated artefacts of a similar geometry are readily available and extrinsic factors are minimized.

6.4 Use of computer simulation (ISO/TS 15530-4)

Computer simulation can be thought of as a virtual substitution technique. The method of simulation, like sensitivity analysis, quantifies each uncertainty source with a distribution of values which can be characterized by statistical properties, e.g. by a standard deviation. However, unlike sensitivity analysis, which is limited to characterizing uncertainty interactions using sensitivity and correlation coefficients, simulation techniques can capture complex interaction among uncertainty sources by employing a mathematical model of the measurement process. This is similar to the substitution technique which naturally includes these interactions by performing the actual measurement. The benefit of computer simulation is derived from repeated simulations of different measurement scenarios, where each scenario involves a specific set of measurement errors (as opposed to uncertainties). The use of specific measurement errors, together with the mathematical model, often allows a more complete description of the interactions, i.e. correlations, between sources than attempting to calculate sensitivity coefficients. (In some cases sensitivity coefficients are impossible to calculate analytically since the measurement process cannot be analytically described). When performing simulations, since the specific measurement errors are not actually known, large numbers of simulation cycles are required to sufficiently characterize the uncertainty sources. The collection of simulated measurement results (one from each simulation cycle) can then be quantified by a standard deviation which yields the combined standard uncertainty.

Simulation techniques can be used when the measurement process can be mathematically described. It is particularly useful when the details of individual uncertainty sources are well known but the interactions between sources are complex. The results of simulation studies are only as valid as the mathematical description of the measurement process. Simulation is often use to model a section of an uncertainty budget involving interacting sources, reducing this complexity to one uncertainty source which can be entered into the uncertainty budget.

See also ISO/IEC Guide 98-3/Suppl.1:2008.

