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BSI Standards Publication

Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment

Part 5: Uncertainty in verification testing of indicating measuring instruments

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National foreword

This British Standard is the UK implementation of EN ISO 14253-5:2015.

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Spécification géométrique des produits (GPS) - Vérification par la mesure des pièces et des équipements de mesure - Partie 5: Incertitude liée aux essais de vérification des appareils de mesure indicateurs (ISO 14253-5:2015)

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European foreword

This document (EN ISO 14253-5:2015) has been prepared by Technical Committee ISO/TC 213 “Dimensional and geometrical product specifications and verification” in collaboration with Technical Committee CEN/TC 290 “Dimensional and geometrical product specification and verification” the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2016, and conflicting national standards shall be withdrawn at the latest by March 2016.

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Endorsement notice

The text of ISO 14253-5:2015 has been approved by CEN as EN ISO 14253-5:2015 without any modification.

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.

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

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

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

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 conformity or nonconformity with specifications*

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

— *Part 3: Guidelines for achieving agreements on measurement uncertainty statements*

— *Part 4: Background on functional limits and specification limits in decision rules*

— *Part 5: Uncertainty in verification testing of indicating measuring instruments*

— *Part 6: Generalized decision rules for the acceptance and rejection of instruments and workpieces* [Technical Report]

Introduction

This part of ISO 14253 belongs to the general geometrical product specification (GPS) series of documents (see ISO 14638). It influences chain link F of all chains of standards in the general GPS matrix.

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

For more detailed information about the relationship of this part of ISO 14253 to other standards and to the GPS matrix model, see Annex B.

Decision rules for deciding conformity or non-conformity to specifications are based on the measurement uncertainty incurred while testing.

Usual practice in measurement familiarizes metrologists and practitioners with measurement uncertainty. Any possible effect that may affect the measurement result is considered and quantified as an uncertainty component and is eventually included in the combined uncertainty. The purpose of the measurement is to gather quantitative information on a given measurand, and the uncertainty statement expresses how reliable that information is.

In the case of tests of indicating measuring instruments, the purpose of the measurement is to investigate one or more metrological characteristics of the indicating measuring instrument rather than to measure characteristics of features of a workpiece. The uncertainty being evaluated in this case, the test value uncertainty, quantifies the accuracy of the test value. The test detects the quality of the indicating measuring instrument, reported through the test values and not through the test value uncertainty.

The test value uncertainty for indicating measuring instruments is not conceptually trivial to evaluate, and careful consideration is necessary to determine which uncertainty components should and which should not be accounted for.

Some tests of indicating measuring instruments may be relative to quantities other than instrument indications, or a single test may investigate both the instrument indication(s) and other metrological characteristics. An example is a test of a micrometer investigating the indication error (subject to an MPE) as well as the measuring force (subject to an MPL). For tests, or portions of them, relative to metrological characteristics other than instrument indications, this part of ISO 14253 is not applicable: they are about quantities for which the application of the ISO/IEC Guide 98-3 (GUM) and of the ISO 14253-2 is conceptually straightforward, with no need of further guidance in this part of ISO 14253.

A rigorous definition of the test value uncertainty when testing indicating measuring instruments is given. Application of conventional uncertainty evaluation based on this definition and according to the ISO/IEC Guide 98-3 (GUM) and the ISO 14253-2 determines which uncertainty components to account for.

Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment —

Part 5: Uncertainty in verification testing of indicating measuring instruments

1 Scope

This part of ISO 14253 specifies concepts and terms for evaluating the uncertainties of the test values derived according to a test protocol agreed upon by the parties and relative to instrument indication(s), obtained in verification testing of GPS indicating measuring instruments.

NOTE The uncertainty of the test values, referred to as test value uncertainty, is not to be confused with the measurement uncertainty associated with using that indicating measuring instrument to measure workpieces. The former only is covered in this part of ISO 14253; for guidance on the latter see the ISO/IEC Guide 98-3 (GUM) and ISO 14253-2.

When a test of an indicating measuring instrument comprises several test values, some relative to the instrument indication and some to other metrological characteristics, this part of ISO 14253 is concerned with the uncertainty of the former only.

This part of ISO 14253 does not provide guidelines to ensure the adequacy of a test protocol; rather, once a test protocol is given, it describes how to evaluate the consequent test value uncertainty.

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 14253-1:2013, *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 1: Decision rules for proving conformity or nonconformity with specifications*

ISO/TR 14253-6:2012, *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 6: Generalized decision rules for the acceptance and rejection of instruments and workpieces*

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

ISO 17450-2:2012, *Geometrical product specifications (GPS) — General concepts — Part 2: Basic tenets, specifications, operators, uncertainties and ambiguities*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99:2007, *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/TR 14253-6, ISO 14978, ISO 17450-2, ISO/IEC Guide 98-3 (GUM), ISO/IEC Guide 99 (VIM), and the following apply.

3.1
test
<of a GPS indicating measuring instrument> sequence of preparatory, measurement, mathematical and decisional actions according to a test protocol

Note 1 to entry: Not all steps in the sequence are necessarily present in a test protocol.

Note 2 to entry: Tests are often used to verify the specifications of a GPS indicating measuring instrument.

Note 3 to entry: The specification of an indicating measuring instrument may be expressed by one or more MPEs (Maximum Permissible Errors).

Note 4 to entry: Prominent cases of tests are the acceptance test and the reverification test.

Note 5 to entry: This term is sometimes used in a wider sense, encompassing cases when a test produces a binary or categorical result. An example of a binary assessment is determining whether or not a software algorithm converged. For the purpose of this part of ISO 14253, tests are restricted to those based on test values.

Note 6 to entry: See Figure 1.

3.2
test instance
combination of test equipment, set up, measurement sequence, environmental and instrumental conditions of a test, which yields a test value(s)

3.3
permissible test instance
test instance in compliance with the test protocol, and with the alternatives and stipulations therein

Note 1 to entry: An alternative occurs when the test protocol allows options, either discrete among enumerated cases, or continuous in a range of permissible values. An example of the former is the choice of the test equipment, e.g. a gauge block or a step gauge for testing a CMM; an example of the latter is the ambient temperature within the required test conditions.

Note 2 to entry: A stipulation occurs when the test protocol specifies the amount of measurement in a test, e.g. a specific number of repeated measurements.

Note 3 to entry: A test may be subject to alternatives and stipulations at the same time. For instance, test equipment is applied to an indicating measuring instrument in a limited number of configurations (stipulation) chosen at the tester counterpart's discretion (alternative).

Note 4 to entry: Alternatives serve two purposes. (1) To accommodate to actual conditions. For instance, alternative test equipment to accommodate actual availability, or any environmental condition within the required test conditions to accommodate the actual testing environment. (2) To leave details of the test unspecified up to the time of testing, to encourage the indicating measuring instrument manufacturer – in order to avoid non-acceptance of the instrument – to deliver overall compliant indicating measuring instruments. For instance, some procedural details may be left to the *tester counterpart* (3.14) to decide at the time of testing, to force the manufacturer to deliver a compliant indicating measuring instrument for any possible procedural option.

3.4
test measurand
metrological characteristic of an indicating measuring instrument intended to be verified in a test, based on a single permissible test instance, defined by a test protocol

Note 1 to entry: A test protocol may allow for multiple permissible test instances, to adapt to actual circumstances and to limit the experimental effort. The test measurand is defined for each single test instance, and different permissible test instances may give raise to different test measurands.

3.5
test protocol
predefined detailed specification of a test which defines the test measurand, the required test conditions and a decision rule

Note 1 to entry: The test protocol is defined either by relevant standards or – when none is available – by the tester or the *tester counterpart* (3.14).

Note 2 to entry: The tester and the tester counterpart are to agree upon the test protocol prior to the test.

Note 3 to entry: A default decision rule is given in ISO 14253-1. See ISO/TR 14253-6 for guidance in defining alternative decision rules.

Note 4 to entry: An unambiguous test protocol is crucial for the effectiveness of a test. In particular, the definition of the set of permissible test instances constitutes a trade-off between thoroughness and practical and economical viability of the test.

Note 5 to entry: As the default rule in ISO 14253-1 is stringent and conservative, in this case the verification approaches a proof in an absolute sense.

3.6
measured test indication
result of a measurement performed in a test, which contributes to the test value according to a test operator

Note 1 to entry: A test value may be based either on a single or on multiple measured test indications, as stipulated in the test protocol.

3.7
test operator
predefined sequence of mathematical and/or statistical operations applied to the measured test indication(s) collected in the test to deliver a test value

Note 1 to entry: Each test value is delivered according to a test operator. In the case of a test yielding multiple test values (see 3.8 Note 4 to entry), as many test operators are needed.

Note 2 to entry: The operations in the sequence can be divided in four broad categories: outlier rejection, noise reduction, statistics, and other mathematical operations.

— Examples of outlier rejection: (1) discarding measured test indications above the 99th percentile of the measured test indications collected in the test; (2) when no more than 2 % of the measured test indications causes failure to meet the specification, repeating those measurement three times.

— Examples of noise reduction: (1) taking the median of repeated measurement values; (2) performing a (spatial) frequency analysis and discarding all wavelengths above a predefined threshold.

— Examples of statistics: taking (1) the mean or (2) the maximum of the absolute values of the measured test indications collected in the test.

— Examples of other mathematical operations: (1) computing a Gaussian (best-fit) sphere associated to the coordinates obtained as measured test indications, and the individual distances of each measured test indication to the sphere centre; (2) computing the mean of the measured test indications taken in a scan over a line.

3.8
test value
quantity value measured in a test estimating the magnitude of a test measurand

Note 1 to entry: A test value is based on the measured test indication(s) and is derived according to the test operator.

Note 2 to entry: A test value cannot usually capture the performance of an indicating measuring instrument in full, because is limited as regulated by the test protocol.

Note 3 to entry: A test value may be derived from several measured test indications, according to the test operator.

Note 4 to entry: A test may yield more than a test value. For example, a test may address several metrological characteristics of an indicating measuring instrument for which MPE's are set, resulting in as many test values.

Note 5 to entry: Figure 1 depicts the case of a test with a single MPE. When more are present in a test, items 3 to 7 are repeated for each MPE.

Note 6 to entry: There may be cases when no MPE is set to compare with. Possible examples are when a dismissed indicating measuring instrument is being reintegrated, or when an MPE originally stated in the data sheet is being adapted to the actual requirements of a company prior to reverification testing. In these cases, items 5 to 7 are missing, and the test terminates with the determination of the test value(s).

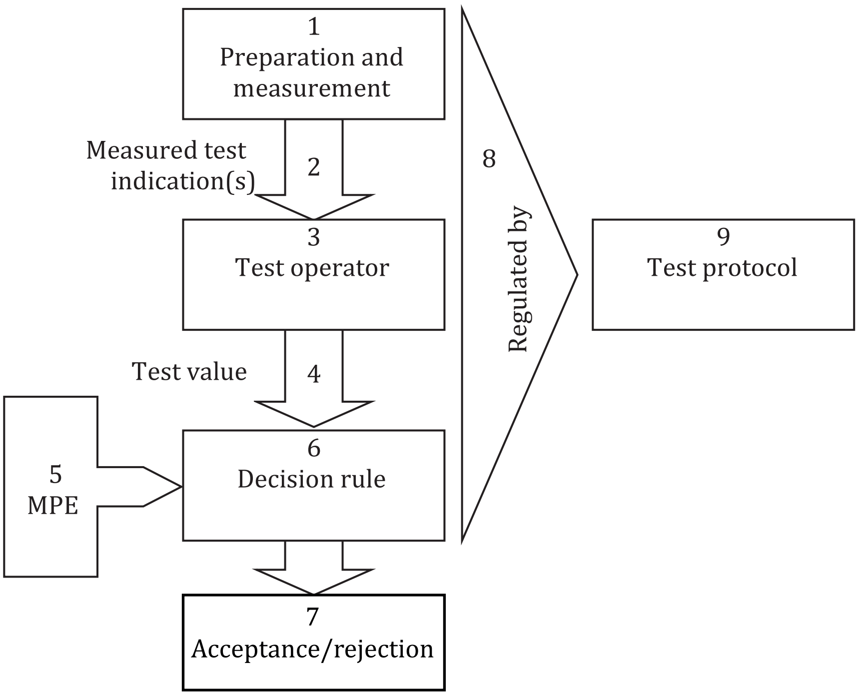

Figure 1 — Schematic of a test

3.9
test value uncertainty
test uncertainty
measurement uncertainty associated to a test value

Note 1 to entry: The test value uncertainty is not a measure of the performance of the indicating measuring instrument under test; the performance is captured by the test values.

Note 2 to entry: The test value uncertainty is commonly used in the application of decision rules.

Note 3 to entry: The test value uncertainty is usually controlled by and is the responsibility of the tester, who usually provides and uses the test equipment. See 7.4 when alternative test equipment is provided by the *tester counterpart* (3.14).

Note 4 to entry: The test value uncertainty does not include any definitional uncertainty due to possible non uniqueness of test values in a permissible test instance. By agreement on the test protocol, the test is valid for any permissible test instance, for each of which a unique test measurand applies (see 3.4 Note 1 to entry).

Note 5 to entry: The test value uncertainty reveals neither the effectiveness of a test protocol in assessing a metrological characteristic, nor the reproducibility of a test value over different permissible test instances.

3.10
test equipment
measuring system and its accessories used in a test, other than the indicating measuring instruments under test and its recognized accessories

EXAMPLE 1 In the test of a micrometer, the test equipment may be a set of gauge blocks.

EXAMPLE 2 In the test of a CMM, the test equipment may be calibrated test lengths and a calibrated sphere with their supports.

3.11
instrument-related input quantity
input quantity affecting a test value, associated with the indicating measuring instrument

EXAMPLE 1 The distributed temperature – and its spatial and temporal gradients – of the indicating measuring instrument.

EXAMPLE 2 The distributed strain due to deformation of the indicating measuring instrument induced by the load of the test equipment weight.

3.12
test equipment-related input quantity
input quantity affecting a test value, associated with the test equipment

EXAMPLE 1 The distributed temperature – and its spatial and temporal gradients – of the test equipment.

EXAMPLE 2 Displacement of the test equipment relative to the indicating measuring instrument occurring during the test (drift and rock), and strain of the test equipment due to fixturing.

Note 1 to entry: While testing indicating measuring instruments, the usual roles in measurement of the indicating measuring instruments and of the workpieces are reversed (what measures what, see the Introduction). Typically, for workpiece measurements, a known accuracy indicating measuring instrument measures an unknown characteristic of the workpiece. But in this part of ISO 14253, known accuracy test equipment is used to measure test values of an unknown accuracy indicating measuring instrument. In light of this, the test equipment-related input quantities are influence quantities (see ISO/IEC Guide 99:2007, 2.52, EXAMPLE 3), while the instrument-related input quantities are not.

3.13
tester
party who performs a verification test

3.14
tester counterpart
party in a test other than the tester

Note 1 to entry: In an acceptance test, the tester counterpart may be either the customer or the supplier, possibly represented by a third party.

Note 2 to entry: In a reverification test, the tester counterpart is the user, possibly represented by a third party.

3.15
tester responsibility criterion
criterion according to which an input quantity is accounted for as a test value uncertainty component if and only if it is controlled by the tester, either directly or indirectly

Note 1 to entry: Examples of uncertainty components under the tester's direct control are the thermal stabilization and the set up of the test equipment.

Note 2 to entry: Examples of uncertainty components under the tester's indirect control are the calibration uncertainties of the test equipment: even if these values are determined by calibration laboratories and not by the tester, the tester controls them indirectly by selecting which equipment, when alternatives are allowed, and which calibration laboratory.

3.16
user-provided quantity value
quantity value provided by the user of an indicating measuring instrument in normal operation, necessary for the indicating measuring instrument to perform as designed

Note 1 to entry: Indicating measuring instruments use user-provided quantity values to compensate for predicted systematic effects, e.g. a user-provided CTE (Coefficient of Thermal Expansion) of the material of the workpiece/artefact is used to compensate for its thermal expansion.

Note 2 to entry: Not all indicating measuring instruments require user-provided quantity values.

Note 3 to entry: A default value may be assigned to a user-provided quantity value, and a user may even not realize the default occurring. For example, the user-provided CTE in Note 1 to entry may default to $11,5 \cdot 10^{-6}$ K^{-1} – typical for steel, taken for the actual compensation unless the user actively inputs another quantity value.

Note 4 to entry: An indicating measuring instrument may let the user choose a user-provided quantity value among a list of predefined values or cases, e.g. in its software interface.

Note 5 to entry: When indicating measuring instruments are tested, the tester is required to provide the user-provided quantity values (if any).

4 General

ISO 14253-1 handles the demonstration of conformity (or nonconformity) to specifications in a uniform way, regardless of whether the specification corresponds to a workpiece (passive in measurement) or to an indicating measuring instrument (active in measurement). No difference is made between the two cases, apart from the specific terms tolerance (for the workpiece) and maximum permissible error (for the instruments) replacing the generic term specification. This uniformity is very valuable, as it provides a unified approach. In both cases, the decision rule is based on the measurement uncertainty, which is an essential part of it.

The evaluation of the measurement uncertainty when testing workpieces might not be simple, but is conceptually straightforward. What is specified and subject to testing is dimensional or geometrical characteristics of one or more features of the workpiece. GPS provides a sophisticated, detailed, unambiguous set of linguistic, symbolic and conceptual tools to specify characteristics of features. All the information needed for the test is contained in the workpiece specification, e.g. the technical drawings. The tester can choose (based, e.g. on economics) between several measurement instruments and techniques to test if a given part conforms to specifications. Alternative testing methods are all intended to deliver the same test value within their different uncertainties.

The evaluation of the measurement uncertainty when testing indicating measuring instruments might be simple, but it is not conceptually straightforward and requires careful consideration. The objective of the testing in this case is to evaluate metrological characteristics of indicating measuring instruments. Even for very simple indicating measuring instruments, the possible measurement tasks are many; for complex indicating measuring instruments (e.g. CMMs), they may be virtually infinite. In addition, the environment may vary over the required test conditions, with impact on the performance. Different permissible test instances may yield different test values. In principle, all possible measuring tasks and environmental conditions should be tested, but this is usually impossible, and certainly not viable economically.

To make a test feasible, well-defined and valuable, a test protocol is needed. The test protocol specifies the test measurand and the requirements needed to fulfil the test, e.g. the measurement procedure, the test equipment, etc. The test protocol is a trade-off between thoroughness and economical viability, often admittedly not providing full coverage of the variables included under MPE rating. To mitigate the lack of coverage for economic reasons, the test protocol may sometimes allow for a family of procedures for acceptance testing, leaving the purchaser freedom to choose one at the time of the test. This way the instrument manufacturer is encouraged to have compliant indicating measuring instruments for any procedure in the family. A good test protocol will cover a high fraction of the indicating measuring instrument performance with a limited effort and cost.

Once the parties agree to use a test protocol, any set of alternatives and stipulations described therein is allowed. The question arises then whether the variability of test values resulting from different permissible test instances is to be accounted for in the test value uncertainty. For example, if the test protocol imposes a limited number of measurements, while more would lead to different test values, the question arises whether this variability is part of the test value uncertainty.

Clauses 5 to 7 of this part of ISO 14253 address this issue and give recommendations on what to account for or not to account for as a test value uncertainty component.

5 Test measurand

5.1 General

The test measurand is an instance of a metrological characteristic of an indicating measuring instrument. Its magnitude is estimated by the test value, usually compared with a specified MPE to decide upon acceptance or rejection of the indicating measuring instrument, taking account of the test value uncertainty. Each permissible test instance defines its own test measurand.

NOTE The same test may consider more than one test measurand, if so regulated in the test protocol. A single test measurand is dealt with hereafter for sake of simplicity; in case of multiple test measurands, what follows applies to each of them.

A test is regulated by a test protocol, which specifies the test measurand and the permissible test instances. The alternatives admit different test instances as equally valid, while the stipulations confine the investigation. A good test protocol should limit alternatives and stipulations as much as feasible, as repeatable test values representative of the full metrological characteristics of indicating measuring instruments are desirable. However, this is usually not fully possible, because it would require excessively long and expensive testing. Based on educated appraisal and experience, the test protocol provides a trade-off between test thoroughness and practical viability, resulting in some alternatives and stipulations to fit actual conditions, and to confine the test to a reasonable amount of effort and cost. The inevitable consequence is that different test instances are permitted, possibly yielding different test values.

In principle, a test that spans all permissible test instances, i.e. with no stipulations, would lead to a complete knowledge of the performance of an indicating measuring instrument with regard to the test measurand.

As infinite measurements are not possible in practice, the test protocol specifies stipulations, e.g. how many measurements. To mitigate this, alternatives are sometimes allowed, among which one is chosen at the time of testing. This way, the indicating measuring instrument manufacturer does not know all details of the actual test instance in advance, and is thus encouraged to make compliant indicating measuring instruments for any permissible test instance to avoid non acceptance. In addition, alternatives may be allowed to fit the actual test conditions and equipment, e.g. any actual ambient temperature within the required test conditions, regardless that other temperatures would be accepted as well.

As a consequence, any permissible test instance may be different from any other, and also different from the ideal case of infinite measurements. It is the responsibility of the test protocol to guarantee that the test value yielded in any permissible test instance is not too different from that in any other or in the ideal case of infinite measurements. The test value yielded in each permissible test instance is an element out of a complete population of possible test values; it is the responsibility of the test protocol to guarantee that this element is sufficiently representative of the full population.

The question may arise whether or not the variability of test values due to lack of representativeness, i.e. across different permissible test instances, contributes to the test value uncertainty. This question is usually the most misunderstood in evaluating the test value uncertainty, generating the most confusion in practitioners.

If the test measurand were defined on the full population of test values from all possible test instances, then the test variability should be part of the test value uncertainty. On the contrary, the test measurand is defined on a single permissible test instance (see 3.4): this means the variability is left outside the definition of the test measurand and thus does not contribute to the test value uncertainty. Each permissible test instance leads to a test measurand; by agreement to the test protocol, parties accept to limit the test to one measurand, deemed representative of the performance of the indicating measuring instrument.

5.2 Input quantities and test measurand definition

This clause is concerned in particular with how an input quantity, e.g. the ambient temperature, can be dealt with in the definition of a test measurand.

Test measurands are defined in test protocols. A good test protocol is able to define representative test measurands and estimate them with the least amount of experimental effort and cost. The definitions of test measurands are ultimately business decisions made by the test protocol authors, e.g. the standard committees. This business discretion stops just after the definition stage: once a test measurand is defined, the derivation of its test value and the evaluation of the test value uncertainty, are fully determined.

A definition of the test measurand may include additional input quantities in two different ways. For each of them, (1) by allowing any quantity value within the required test conditions or (2) by specifying an exact quantity value. The former case would result in a sentence in the test protocol like, “The test shall be performed within the required test conditions; any of which is equally valid and sufficient to complete a valid test”. In the latter case the sentence would be like “The test measurand is defined at the exact quantity value x of the input quantity X, i.e. in the hypothetical occurrence of X exactly at x”.

Allowing any input quantity value within the required test conditions is an alternative, to perform the test when the input quantity takes any quantity value within the required test conditions: each leads to a permissible test instance, and hence to a specific test measurand. The test protocol treats each of these measurands as having a unique value and hence the variation in the measurand at different input quantity values is not an uncertainty source, rather the measurement of a different measurand. Typically, all these measurands (within the required test conditions) are given specifications with a single MPE.

EXAMPLE 1 The test is performed with the ambient temperature within the required test conditions, e.g. in the range (20 ± 5) °C and with spatial gradients no greater than 2 °C/m.

EXAMPLE 2 The test is performed by a tester sufficiently trained and skilful, e.g. awarded third party recognition of professional skill.

NOTE 1 EXAMPLE 2 is deliberately loose: while setting thresholds for testers’ skills may be difficult and not clear-cut, still the principle holds clearly that any level of skill above a threshold makes the actual test instance permissible, having no input to the test value uncertainty.

When the test protocol requires that an exact input quantity value is specified, then the test measurand is defined precisely at a predefined input quantity value, with the purpose of not including variations in this influence in the definition of the test measurand. In an actual test, the input quantity will not match the predefined input quantity value exactly: it may be close, but not exactly equal. Hence, a (hopefully small) deviation occurs of the actual input quantity to the predefined input quantity value: the test value shall be corrected to the exact value defined in the test measurand and the correction will involve an uncertainty component accounted for in the test value uncertainty.

EXAMPLE 3 The test measurand is defined at ambient temperature of 20 °C with no spatial gradients (i.e. with spatial gradients equal to 0 °C/m).

EXAMPLE 4 The test measurand is defined with test equipment having no mass (i.e. with a mass equal to 0 kg).

NOTE 2 When the predefined input quantity value is null, the test protocol might take that for granted implicitly. For instance, correct fixturing of the reference standard used in a test may not be explicitly required. A possible sentence requiring that explicitly might be “The test measurand is defined with no rock or strain occurring to the reference standard due to loose or improper fixturing”. It is recommended to resort to implicit specification in test protocols as little as possible to avoid possible misunderstanding, and only in self-evident cases.

The developers of test protocols should have carefully considered the advantages and disadvantages of the two alternatives above carefully, prior to specifying a test protocol. In particular

— Allowing any input quantity value within the required test conditions, releases the tester from any responsibility on that input quantity in the actual test conditions, and particularly from evaluating any correction and its uncertainty. On the other hand, the test value suffers from imperfect reproducibility, as the allowed variability of the input quantity results in some variability of the test value, and

— Specifying an exact input quantity value improves the reproducibility of the test value, as the effect of the input quantity is compensated for. On the other hand, the tester is required to evaluate both the correction and its uncertainty.

In short, allowing a range leads to an easier but less reproducible test, whereas specifying an exact input quantity value to a more reproducible but also more expensive test, with possible limitations to future use of the MPE’s.

The most conceptually straightforward situation occurs when the input quantity is a test equipment-related input quantity. In this case, the input quantity is fully under the tester’s responsibility and control in this case, and the tester is expected to be able to predict the effects of the input quantity and to compensate for them, as well as to evaluate the associated test uncertainty.

Very great care should be taken instead when the test measurand is defined at a predefined input quantity value of an instrument-related input quantity. In this case, the required correction and its uncertainty are relative to the indicating measuring instrument under test. This may raise the following problems:

— Testing is about verifying experimentally the performance of an indicating measuring instrument, as opposed to predicting it. On the contrary, the required correction is based on prediction.

— Indicating measuring instruments under test are considered black boxes as far as possible; on the contrary and to the needed extent, predictions/corrections require disclosure and opening of the black boxes.

— The verification of an indicating measuring instrument against an MPE remains valid afterwards only when the indicating measuring instrument is corrected for the effect of the input quantity as it was during the test. This burdens the tester (in testing) as well as the user (in normal use) with the compensation. When users are not prepared or would not like to do so, e.g. with simple hand-held indicating measuring instruments, actual indication errors may be (much) larger than predicted by the verified MPE’s.

The importance of the above problems increases with the complexity of the indicating measuring instrument under test. For example, predicting the indication error and its uncertainty due to an instrument-related input quantity could be simple enough for a vernier calliper, while is far beyond any reasonable testing effort for a laser tracker or a CMM. In fact the former is simply made of two uniform-material solid pieces, while the latter are assemblies of several undisclosed components with (servo-) active electronic and pneumatic facilities and real time software compensation.

It is recommended that defining a test measurand at a predefined instrument-related input quantity value, if so wished by parties, is restricted to simple indicating measuring instruments, whose structural details are self-evident or disclosed enough to evaluate the compensation and its uncertainty.

6 Tester responsibility criterion

When evaluating the test value uncertainty in practice, a decision shall be made for individual candidate input quantities as to their inclusion as test value uncertainty components. While the theoretical background is given in Clause 5, it may be convenient to have a simple and practical criterion to base the decision on.

A general principle of decision rules is that the liability of the uncertainty is always on the party performing the measurement. The rationale for this is that the test value uncertainty effectively corrupts the test value, and testers are motivated to keep the test value uncertainty to a minimum, to avoid putting the test outcome and the related work at risk.

In other words, testers are responsible for any imperfection which may occur during the test, and pay for it in terms of test value uncertainty. A desired corollary of this is that only what testers are responsible for should be charged to them, i.e. accounted for as a test value uncertainty component.

This constitutes the tester responsibility criterion: any input quantity shall be considered a test value uncertainty component if and only if it is controlled by the tester, either directly or indirectly (see Notes to entry in 3.15).

EXAMPLE 1 A reference standard in a test is fixtured, e.g. a hemisphere to a roundness instrument or a step gauge to a CMM. The test measurand defined in the test protocol assumes no rock of the reference standard relative to the indicating measurement instrument: rock is not among the alternatives recognized in the test protocol. As a consequence, a test value uncertainty component should be considered for (loose) fixturing, to account for the imperfect realization of the test measurand. The tester responsibility criterion leads to the same conclusion: fixturing is fully controlled by the tester, who takes responsibility through a proper test value uncertainty component.

EXAMPLE 2 An indicating measuring instrument is specified in rated operating conditions spanning the ambient temperature range (20 ± 5) °C, and no user-provided quantity values are required by the instrument. The test protocol sets the required test conditions as identical to the rated operating conditions and allows to run a permissible test at a single temperature therein. This stipulation makes any test at temperatures within this interval a permissible test instance, and refines the corresponding test measurand. As a consequence, the actual temperature does not create a test value uncertainty component, as the test measurand is in fact defined just at that temperature. The tester responsibility criterion leads to the same conclusion: it is the test protocol that allows any temperature within the required test conditions; hence, he/she is not responsible, and no test value uncertainty component is to be accounted for.

EXAMPLE 3 As in EXAMPLE 2, but the instrument software requests a workpiece CTE as a user-provided quantity value to compensate for thermal expansion. As in EXAMPLE 2, no test value uncertainty component is to be accounted for the actual ambient temperature (within the required test conditions). However, a test value uncertainty component accounting for the CTE may be considered, whose sensitivity coefficient is a function of the workpiece temperature. The actual ambient temperature should be measured and recorded, and the sensitivity coefficient to the CTE evaluated accordingly.

The tester responsibility criterion leads to the same conclusion on whether an input quantity is a test value uncertainty component, as the definition of the test measurands (Clause 5), unless either of the two following specific circumstances occurs.

— When a test protocol defines a test measurand at an exact instrument-related input quantity value. The tester is required to evaluate a correction and its uncertainty; according to the test measurand definition, this input quantity is a test uncertainty component. However, there may be cases when the tester is not in control of the input quantity, resulting in the tester responsibility criterion excluding the tests uncertainty component which should be included instead.

EXAMPLE 4 As in EXAMPLE 3 in 5.2, when the test takes place at the tester counterpart's site. The required correction for the actual ambient temperature introduces a test value uncertainty component. However, the tester is not in control of the ambient temperature found at the tester counterpart's site, in conflict with the tester responsibility criterion.

EXAMPLE 5 As opposed to EXAMPLE 4, the test takes place at the tester's site. This is usually the case of hand-held indicating measuring instruments tested before sale at the manufacturer's laboratory. The tester controls the ambient temperature, which eliminates the conflict with the tester responsibility criterion.

— When a test protocol defines a test measurand at any test equipment-related input quantity value within the required test conditions. The alternative for the test equipment relieves the tester from accounting for a specific test uncertainty component. However, the test equipment is usually provided by the tester, who takes responsibility of it, resulting in the tester responsibility criterion including the tests uncertainty component which should be excluded instead.

EXAMPLE 6 As in EXAMPLE 2 in 5.2. This is usually the case with manually operated indicating measuring instruments, e.g. articulating arm CMMs. The alternative regarding the tester's skill removes the need to account for a specific test value uncertainty component. However, the tester is fully responsible for his/her skill, in conflict with the tester responsibility criterion.

In deciding whether or not an input quantity is to be accounted for as a test value uncertainty component, the tester responsibility criterion alone is sufficient in general. But, it is not sufficient when either of the above two circumstances occurs, in which case, the test measurand definition shall prevail in the decision (see Table 1).

Table 1 — Reliability of the tester responsibility criterion for an input quantity, in different circumstances

		Test measurand defined for an input quantity having	
		any quantity value within the required test conditions	**an exact quantity value**
Input quantity	Test equipment-related	Full reliability not ensured (possible false inclusion)	Reliable
	Instrument-related	Reliable	Full reliability not ensured (possible false exclusion)

In case of doubt or controversy, the approach based on the definition of the test measurands, as explained in Clause 5, prevails and should be taken as a reference.

7 Specific issues in testing indicating measuring instruments

7.1 General

7.2 to 7.4 answer specific questions which may arise in evaluating the test value uncertainty.

7.2 Errors of the indicating measuring instrument

Are the errors of the indicating measuring instrument (e.g. systematic errors, hysteresis, non perfect repeatability, etc.) contributors to the test value uncertainty?

Indicating measuring instruments are active in measurement and introduce errors. In usual operation, i.e. when the measurands are characteristics of a workpiece being measured, these errors affect the accuracy of the measurement results, and therefore need to be accounted for in the measurement uncertainty associated with the workpiece measurement.

When indicating measuring instruments are tested, they are still subject to these errors. However, the test measurands as defined by the test protocol pertain now to the indicating measuring instruments. Therefore, the errors they introduce are part of the test measurand (unless differently stipulated in the test protocol), and not included in the test value uncertainty associated with the test value.

7.3 Errors in user-provided quantity values

Are the errors due to non exact user-provided quantity values (e.g. the air humidity in an interferometric system equipped with a weather station measuring the air temperature and pressure only) contributors to the test value uncertainty?

Some indicating measuring instruments may require user-provided quantity values to perform as designed. These quantity values are of quantities affecting the measurand, e.g. the coefficient of thermal expansion of a workpiece, or of influence quantities. The indicating measuring instruments use the user-provided quantity values to compensate for estimated systematic effects, e.g. the differential thermal expansion of the measured workpiece to the indicating measuring instrument scale(s). Any error in the user-provided quantity values results in errors of indication of the indicating measuring instrument, or, when the instrument is being tested, in errors in the test values.

NOTE Indicating measuring instruments may perform other automatic compensations that require no action from the user, e.g. for the nonlinearity of a transducer or for geometrical errors of a CMM.

When testers test indicating measuring instruments, they provide the user-provided quantity values, if the instruction manuals of the indicating measuring instrument, or common practice, so require. In this case, the indicating measuring instrument specifications shall be assumed as stated in the absence of any error in the user-provided quantity values. Therefore, a test uncertainty component shall be considered in the test value uncertainty to account for the user-provided quantity values. This is consistent with the tester responsibility criterion, as the tester bears the responsibility for the user-provided quantity values.

Some indicating measuring instruments may support the user in providing the user-provided quantity values by selection from a list of predefined values or cases, e.g. in the software interface. If an option is available (e.g. “others”) to input an actual user-provided quantity value, the tester shall do so even if the quantity value is mentioned in the list; otherwise the closest option shall be chosen. In either case, the related input uncertainty component to the test value uncertainty shall be evaluated based on the tester’s knowledge of the quantity value and not on the information shown in the list of options.

EXAMPLE An indicating measuring instrument may require the user to select the coefficient of thermal expansion of the workpiece under measurement in a list of predefined materials. The tester knows that the reference standard used for the test is made of steel having a coefficient of thermal expansion of $10{,}9 \cdot 10^{-6}$ K^{-1} with a standard uncertainty of $0{,}2 \cdot 10^{-6}$ K^{-1}. If the option exists to input an actual quantity value, then the tester will input $10{,}9 \cdot 10^{-6}$ K^{-1}, otherwise choose the option “steel”. In both cases, the input uncertainty component to the test value uncertainty will be $0{,}2 \cdot 10^{-6}$ K^{-1}.

Automatic compensations with no request for user-provided quantity values shall be regarded as integral parts of the indicating measuring instruments, and their specifications assumed as including these compensations. No such component shall be included in the test value uncertainty. This is also consistent with the tester responsibility criterion, as the tester bears no responsibility in this case.

Indicating measuring instruments compensate for the estimated systematic effects either in software or by other adjustable counteracting systematic effects. To propagate the input uncertainty of user-provided quantity values, the underlying equation should be used as an analytical model, either implemented in the compensation software or describing the counteracting effects. If this is not known, the indicating measuring instrument manufacturer should be contacted. Alternatively, the equation may be assumed based on the tester’s experience and knowledge, in simple and obvious cases, i.e. when a widely recognized model is available for the correction. This is the case, e.g. for the well-known linear model of thermal expansion.

7.4 Using alternative test equipment

Is the tester counterpart allowed to provide test equipment in an acceptance test? If so, how is the test value uncertainty dealt with?

In principle, any properly calibrated test equipment is equivalent to any other within its calibration uncertainty. Therefore, the tester counterpart may want to have a specific test equipment used in the test, as a further guarantee of the test transparency.

NOTE This situation cannot occur in a reverification test, as the tester and the tester counterpart coincide in that case.

Even if nominally physically equivalent, test equipment provided by the parties may have different calibration uncertainties. When the tester counterpart's uncertainty is larger than the tester's, this may alter the outcome of the test, according to a decision rule.

When the tester counterpart proposes alternative test equipment, then two complete budgets of the test value uncertainty at the time of use shall be evaluated, one for each test equipment. When relevant, values of temperature and of any other environmental parameter deemed representative of the actual situation are assumed by mutual agreement. The tester is then obliged to use the tester counterpart's test equipment-only if the related test value uncertainty is no greater than that of the tester's. In any case, the test value uncertainty associated to the test equipment actually chosen shall be used.

The tester counterpart wanting to use alternative test equipment shall document the calibration of such equipment to the extent required for the test, and specifically the calibration uncertainty.

Since the tester is usually prepared to perform the test with his/her own test equipment, the use of the tester counterpart's may require additional time and labour. The additional costs and the two test value uncertainty budgets should be agreed upon during the contract negotiations; see Annex A for specific guidance.

In all cases, the tester bears the responsibility of the test value uncertainty, including its component due to the test equipment, even if it is provided by the tester counterpart.

Annex A
(informative)

Guidance on using alternative test equipment

Subclause 7.4 deals with the case when a tester counterpart proposed alternative test equipment in a test, for sake of additional transparency. This Annex gives additional guidance on this occurrence.

The complexity of test equipment may range from very simple (e.g. a few gauge blocks for testing a vernier calliper) to very complex (e.g. a laser interferometer with articulation facilities and auxiliary weather station, for a large CMM). Particularly in the latter case, a tester may organize his/her work by means of a “toolbox”, including fixturing equipment optimized for the reference standards used in the test, software, procedures, etc.

The general rule is that the tester counterpart wanting to use alternative test equipment addresses the additional complications that this creates, including providing sufficiently accurate equipment, and incurs the marginal cost of

— alternative reference standards with documented calibration (when required in the test),

— adequate supports and fixturing, when the testers do not fit the alternative reference standards,

— a detailed procedure, when any deviation from the tester’s is necessary,

— adequate software – or portions of it – to run the test, when any software is necessary at all in the test and when the testers is unable to manage the alternative equipment, and

— labour to implement any deviation from the tester’s usual procedure, particularly when the test is run by an operator, possibly at the tester counterpart’s site, trained and qualified for the standard procedure only.

EXAMPLE 1 A micrometer is tested based on the measured test indications obtained from a set of gauge blocks and of plug gauges. In this case, no special fixturing is necessary, the procedure is straightforward and possibly standardized, the instrument has got no computer acquisition facility, and the software used by the tester to run the test has manual input (e.g. a spreadsheet). Provided that the user counterpart’s alternative gauges are of proper size and calibrated with sufficient accuracy, no special hindrance is expected in this case in using alternative test equipment.

EXAMPLE 2 A CMM is tested according to ISO 10360-2 using a set of gauge blocks. As the size and grade of gauge blocks are standardized by ISO 3650, no special hindrance is expected in substituting the testers with the tester counterpart’s of the same nominal values and grade.

EXAMPLE 3 As in EXAMPLE 2, but a step gauge is used instead of gauge blocks. There is no international standard regulating step gauges, and different brands differ significantly in geometry to the point that the supporting equipment and fixturing for one may be inadequate or unusable for another. Furthermore, the datum features used to set the gauge reference frame are brand-dependant and require specialized portions of the CMM part programme used to run the test. Agreeing upon and clearing all these details prior to the test is very important in this case, in order to minimize wasted time and to prevent controversies. When instead the tester’s and the tester counterpart’s step gauges are of a same brand and nominally identical and have no greater calibration uncertainty, no special hindrance is expected.

EXAMPLE 4 As in EXAMPLE 2, but an alternative laser interferometer is used instead of gauge blocks. Laser interferometers are very different from gauge blocks in many respects, including the needs for: fixturing with possible articulation facilities, air refraction compensation by means of, e.g. a weather station; equipment to attach a(n articulating) retroreflector to the ram or dedicated sliding equipment; additional material standards of size like, e.g. gauge blocks; dedicated acquisition software; and specific competence. Apart from special cases when the tester is very flexible and competent, he/she is unlikely to be able to run the test at all. If the tester counterpart takes direct control and run the test him/herself, this would reverse the tester's and the tester counterpart's roles, with consequences on the use of the test value uncertainty in the decision rule according to ISO 14253-1. Unless very detailed agreements are made prior to the test, such a dramatic change in test equipment is unlikely to be feasible.

In all cases, any change in the tester's standard procedure is accounted for and reflected in the test value uncertainty, by updating the magnitude of, or by adding, or by deleting test value uncertainty components.

It is recommended that the tester counterpart's intention of using alternative test equipment is disclosed and agreed upon prior to the test, to minimize the risk of last minute disagreements. This includes all details on the possible practical hindrances above, on the update of the test value uncertainty budget, and on any arising economical implications.

Annex B
(informative)

Relation to the GPS matrix model

B.1 General

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

The ISO/GPS matrix model given in ISO 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.

B.2 Information about this part of ISO 14253 and its use

This part of ISO 14253 provides guidance for applying the decision rules of ISO 14253-1, by explaining the evaluation of the test value uncertainty.

B.3 Position in GPS matrix model

This part of ISO 14253 belongs to the general GPS series of documents, and influences chain link F of all chains of standards, as graphically illustrated in Table B.1.

Table B.1 — Position in the GPS matrix model

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

B.4 Related standards

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

Bibliography

[1] ISO 3650:1998, *Geometrical Product Specifications (GPS) — Length standards — Gauge blocks*

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

[3] ISO 10360-2:2009, *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 2: CMMs used for measuring linear dimensions*

[4] 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*

[5] ISO 14638:2015, *Geometrical product specifications (GPS) — Matrix model*

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