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Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring systems (CMS) —

Part 11:
CMSs using the principle of X-ray computed tomography (CT)

Spécification géométrique des produits (GPS) — Essais de réception et de vérification périodique des machines à mesurer tridimensionnelles (MMTs) —

Partie 11: MMTs utilisant le principe de la tomographie informatisée (CT)

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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 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see https://www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

A list of all parts in the ISO 10360 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO/TR 14638). It influences link 5 of the chains of standards on size, distance, radius, angle, form, orientation, location, run-out and datums.

For more detailed information of the relation of this document to other standards and the GPS matrix model see Annex I.

In close reliance on ISO 10360-2 and ISO 10360-5 for coordinate measuring systems (CMSs) equipped with contact probing systems as well as ISO 10360-8 for CMSs with optical distance sensors, this document specifies the acceptance and reverification tests for verifying the performance of CMSs that use the principle of X-ray computed tomography (CT). Where technically possible, the testing methodology of these parts of ISO 10360 is intended to be similar.

The metrological characteristics described in this document serve both for the specification of CMSs that use the principle of CT and for comparison between various coordinate measurement systems. This document is intentionally dedicated to CMSs that use CT where measurements are predominantly based on the attenuation contrast visible when penetrating physical matter. This document may also be applied to CMSs which use other tomographic measurement principles based on a mutual agreement.

Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring systems (CMS) —

Part 11: CMSs using the principle of X-ray computed tomography (CT)

1 Scope

The purpose of this document is to define metrological characteristics and methods for testing CMSs that use the principle of CT (based on X-ray attenuation contrast) as a single sensor and which are dedicated to dimensional measurements of technical workpieces. This excludes medical imaging, medical dimensional measurements and native non-destructive (material) testing applications of CT (e.g. defect analyses). The intention of this document is to achieve – where possible – comparability with the metrological characteristics of CMSs employing tactile probes and/or optical sensors.

CMSs which use sensors other than CT are covered by this document if such sensors are used for setting up and preparing measurements for which CT is used, only.

NOTE CMSs which use other sensors together with CT to perform measurements can be specified and tested using ISO 10360-9.

This document covers CMSs which use CT as a measurement technology and which employ various hardware configurations (Annex A) and different scanning modes (Annex B). This document defines metrological characteristics and methods for testing maximum permissible errors (MPEs) that are intended specifically for non-gradient, homogeneous mono-materials, i.e. measurements of reference standards that consist of only one (relevant) material that has no relevant lateral or spatial gradient in the attenuation of X-rays.

This document does not define metrological characteristics or related testing methods that are dedicated to measuring the influence of surface roughness on CT-based CMS measurements or vice-versa (measuring roughness with CT-based CMSs).

For measuring limits of lateral structures below a certain resolution limit, Annex E mentions two types of resolution statements which the manufacturer provided as optional metrological characteristics.

This document establishes the following aspects necessary when using CT:

— Reference standards usable as alternatives to gauge blocks (Annex C)

— Definition of metrological characteristics for various operating conditions

— Notes on the impact on the measurement of, for example, environmental conditions, mathematical data filters and the nature of the measurement standard's surface

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes the requirements 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 1, *Geometrical product specifications (GPS) — Standard reference temperature for the specification of geometrical and dimensional properties*

ISO 3650, *Geometrical Product Specifications (GPS) — Length standards — Gauge blocks*

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

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

ISO 10360-5, *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring systems (CMS) — Part 5: Coordinate measuring machines (CMMs) using single and multiple stylus contacting probing systems using discrete point and/or scanning measuring mode*

ISO 10360-8, *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring systems (CMS) — Part 8: CMMs with optical distance sensors*

ISO 10360-9, *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring systems (CMS) — Part 9: CMMs with multiple probing systems*

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

ISO 14253-5, *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 5: Uncertainty in verification testing of indicating measuring instruments*

ISO/TS 17865, *Geometrical product specifications (GPS) — Guidelines for the evaluation of coordinate measuring machine (CMM) test uncertainty for CMMs using single and multiple stylus contacting probing systems*

ISO/TS 23165, *Geometrical product specifications (GPS) — Guidelines for the evaluation of coordinate measuring machine (CMM) test uncertainty*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

ISO/TR XXXXX, *Resolution statements for dimensional measurements of CMSs using the principle of X-ray computed tomography (CT)* (see Annex E)

3 Terms and definitions

For the purposes of this document, the terms and definitions given in VIM and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

This document describes physical material measures used for the measurement of the metrological characteristics. In this document, the physical material measures are denoted as “reference measurement standards” or “reference standards” for short (see VIM). This document uses – in contrast to other standards and guidelines – the expression “artefact” only for imaging errors of the CMSs, as this meaning and expression is common in the field of CT. For probing error assessment, a calibrated sphere is used; this reference standard will be denoted as the “test sphere”. For assessing length measurement errors, various types, different reference standards may be used (Annex C). When referring to a single length assessed with a standard, the expression “test length” is used. For the readability of this document, the term “Gaussian” refers to an unweighted least-squares fit without any constraint (position or diameter, if applicable).

3.1
material class
j
Designation of material class j. The metrological characteristic associated with material class j shall be measured with a reference standard and an obstructive body – if applicable – both made from a material within the respective material class definition, j (j = Pl for class “plastic”, j = Al for class “aluminium”, j = Fe for class “steel”; see 5.6)

Note 1 to entry: An obstructive body is an uncalibrated, separate piece of material placed next to a reference standard to adjust the penetration length (see Table 2) of the material seen by X-rays in individual projections of a CT scan. 5.6 describes criteria for the material of the obstructive body and, if required, the mounting material (5.6.3).

Note 2 to entry: Occasionally, the acquisition of a complete set of X-ray projections of a single CT measurement is called a CT scan.

Note 3 to entry: j = Fe is deduced from chemical symbol Fe for iron, the major component of steel.

3.2
probing form dispersion error
$P_{\text{Form.Sph.D95\%.j::CT}}$
smallest possible width of a spherical shell which contains 95 % of all data points measured on a test sphere of *material class* j (3.1)

Note 1 to entry: The “D” inside ‘D95%’ indicated that the characteristic feature of this metrological characteristic is the “dispersion” of the population, while the “95%” inside ‘D95%’ refers to the coverage of 95 % of all points.

3.3
probing form error All
$P_{\text{Form.Sph.All.j::CT}}$
smallest possible width of a spherical shell which contains all data points measured on a test sphere of *material class* j (3.1)

3.4
probing size error All
$P_{\text{Size.Sph.All.j::CT}}$
error of indication of the (signed) difference between the diameter of a least-squares fit of all points measured on a test sphere of *material class* j (3.1)and its calibrated diameter

3.5
volumetric length measurement error
$E_{\text{Vol.j::CT}}$
error of indication when measuring a calibrated test length where the error is deduced from the distance between two points each determined from multiple measurement points of two respective geometrical elements on a reference standard of *material class* j (3.1)

Note 1 to entry: The absolute value of the volumetric length measurement error is in nearly all cases smaller than the bidirectional length measurement error.

3.6
maximum permissible probing form dispersion error
$P_{\text{Form.Sph.D95\%.j::CT,MPE}}$
MPE of $P_{\text{Form.Sph.D95\%.j::CT}}$

3.7
maximum permissible probing form error All
$P_{\text{Form.Sph.All.j::CT,MPE}}$
MPE of $P_{\text{Form.Sph.All.j::CT}}$

3.8
maximum permissible probing size error All
$P_{Size.Sph.All.j::CT,MPE}$
MPE of $P_{Size.Sph.All.j::CT}$

3.9
maximum permissible volumetric length measurement error
$E_{Vol.j::CT,MPE}$
MPE of $E_{Vol.j::CT}$

3.10
pre-knowledge
prior knowledge according to 5.8 of the reference standard and/or the obstructive body being measured in acceptance testing that is not directly acquired by the CMS under test but could affect the points measured of the reference standard

Note 1 to entry: Examples of pre-knowledge include nominal chemical composition and CAD-related information such as nominal geometry, nominal surface normal vectors, material information and nominal dimensions.

Note 2 to entry: Metrological characteristics and respective MPE values which are assessed or specified with the use of pre-knowledge receive a test qualifier, 'PreK' or 'CAD', after the first colon.

Note 3 to entry: In case that there are other test qualifiers to be inserted, the test qualifiers 'PreK' or 'CAD' shall be the first after the colon.

Note 4 to entry: The 'CAD' test qualifier indicates pre-knowledge restricted to only CAD-related information – without any specific material designation or chemical composition knowledge. The qualifier PreK allows CAD-related information and more, making CAD-related information a subset of PreK information.

Note 5 to entry: Examples of metrological characteristics where the explicit use of pre-knowledge is indicated by a 'PreK' test qualifier are $P_{Form.Sph.D95\%.j:PreK:CT}$ and $E_{Bi.j:PreK:CT}$, with respective MPE values $P_{Form.Sph.D95\%.j:PreK:CT,MPE}$ and $E_{Bi.j:PreK:CT,MPE}$. The use of a 'CAD' qualifier is similar.

Note 6 to entry: The auxiliary quantity $E_{Bi.shrt.j:PreK:CT}$ may contain also a 'PreK' (or similarly 'CAD') test qualifier. However, there is no attributed MPE value for this quantity.

4 Symbols and abbreviated terms

For the purposes of the main part of this document, the symbols in Table 1 and Table 2 apply.

NOTE Table D.1 contains symbols of optional metrological characteristics and auxiliary quantities used in the Annexes of this document.

Table 1 — Symbols of mandatory metrological characteristics

Symbol	Name	References in this document
$P_{Form.Sph.D95\%.j::CT}$	probing form dispersion error	3.2, 3.6, 5.1, 6.2, 7.1, 7.2, 7.3.3, 9, Annex D.3.4.4.3, Annex H
$P_{Form.Sph.All.j::CT}$	probing form error All	3.3, 3.7, 5.1, 6.2.1, 6.2.3.1, 6.2.3.3, 7.1, 7.2, 7.3.3, Annex D.3.3.3, Annex H
$P_{Size.Sph.All.j::CT}$	probing size error All	3.4, 3.8, 5.1, 6.2, 7.1, 7.2, 7.3.3, Annex D.3.4.4.3, Annex H

Table 1 *(continued)*

Symbol	Name	References in this document
$E_{Vol.j::CT}$	volumetric length measurement error	3.5, 3.9, 5.1, 6.3, 7.1, 7.2, 7.3.3, Annex C, Annex D.1, Annex D.3.4.1, Annex D.3.4.4.2, Annex F.1, Annex F.2
$P_{Form.Sph.D95\%.j::CT,MPE}$	maximum permissible probing form dispersion error	3.6, 5.1, 6.2.4, 7.1, 7.2, 7.3.3, 9
$P_{Form.Sph.All.j::CT,MPE}$	maximum permissible probing form error All	3.7, 5.1, 6.2.4, 7.1, 7.2, 7.3.3
$P_{Size.Sph.All.j::CT,MPE}$	maximum permissible probing size error All	3.8, 5.1, 6.2.4, 7.1, 7.2, 7.3.3
$E_{Vol.j::CT,MPE}$	maximum permissible volumetric length measurement error	3.9, 6.3.4, 7.1, 7.2, 7.3.3, Annex F.1

Table 2 — Symbols of auxiliary quantities

Symbol	Name (with annotation) & note(s)	References in this document
V	measurement volume Note 1 to entry: The measurement volume is often a cylinder, but not always. Often CMSs feature a cylindrical measurement volume where height and diameter of the cylinder are equal, but there exist also CMSs which use X-ray detectors with different height and width. For these CMSs the height and diameter of the cylindrical measurement volume is different.	5.1, 6.1.2
V_1	minimum measurement volume (specified with MPEs) Note 1 to entry: Measurement volume V_1 corresponds to geometrical magnification M_1.	5.1, 6.1.2, Annex H
V_2	maximum measurement volume (specified with MPEs) Note 1 to entry: Measurement volume V_2 corresponds to geometrical magnification M_2.	5.1, 6.1.2, Annex H

Table 2 *(continued)*

Symbol	Name (with annotation) & note(s)	References in this document
L_p	Maximum penetration length through the reference standard, obstructive body (if applicable) and any auxiliary material (if present) when collecting projection images of a single CT scan. Note 1 to entry: The "penetration length" is the individual path length of any X-ray through any matter (in a way similar to that described for L_p), i.e. through the reference standard, obstructive body (if applicable) and any auxiliary material (base mount, temperature sensors, cables, etc. ; if present), when collecting projection images of a single CT scan. The penetration length is counted (i.e. summed) for rays having a line trajectory from the X-ray source to a specific detector pixel. The penetration length is different for any pixel of the detector and also varies with rotation angle for each projection of a single CT scan. All penetration lengths are smaller than or equal to L_p. The minimum penetration length is usually nearly zero (for rays passing through air only; such rays are always present for standard CT scanning). Note 2 to entry: If different materials allowed for testing are penetrated (i.e. materials of material class j and respective substitute materials of material class j), the lengths penetrated in each material are added to obtain L_p. Note 3 to entry: If "other materials" (i.e. auxiliary materials) than those mentioned in the previous note are penetrated, for each material length penetrated through this material a comparable length of a material from material class j must be attributed. A comparable length from a material from material class j creates the same absorption as the "other material" being penetrated. Lengths according to Note 2 to entry: and according to Note 3 to entry: are added to obtain L_p. Note 4 to entry: It is against the intention of the acceptance test to let the lengths according to Note 3 to entry: make a significant contribution to L_p.	5.1, 5.6.3, 6.1.2, Annex D.3.4.4.2
$L_{p,max}(j)$	Manufacturer-specified maximum for L_p (as a rated operating condition) for measuring reference standards made from material class j; material identification is given in brackets. The statement of $L_{p,max}$ (j) shall be made together with respective X-ray parameters (e.g. X-ray tube voltage, X-ray tube power, prefilter material and thickness and exposure time) and measurement parameters. Note 1 to entry: $L_{p,max}(j)$ is an attribute to all metrological characteristics, i.e. length measurement errors, probing errors, resolution statements. Note 2 to entry: $L_{p,max}(j)$ depends on the selected measurement parameters. Note 3 to entry: Providing $L_{p,max}$ (j) together with respective X-ray parameters and respective measurement parameters should enable the user to measure a workpiece with a maximum penetration length of $L_{p,max}$ (j) from a given material. Note 4 to entry: $L_{p,max}$ (j) can have different values for different measurement volumes.	5.1, 6.1.2, 6.2.2.1, 6.3.3.1, Annex D.3.4.3, Annex D.3.4.4.2, Annex D.3.4.4.3, Annex H
τ	Single CT scan projection measurement time (time to assess all projections for acceptance testing of a single CT scan)	5.5
τ_{min}	Minimum value of τ (as specified by the manufacturer)	5.5, Annex H
τ_{max}	Maximum value of τ (as specified by the manufacturer)	5.5, Annex H

Symbols for metrological characteristics assessed with explicit pre-knowledge

Metrological Characteristics of types as explained above, which have been assessed with explicit pre-knowledge (see 5.8) receive the test qualifier 'PreK' or 'CAD' after the first colon.

NOTE The same test qualifier 'PreK' or 'CAD' can also be used for optional metrological characteristics described in Annex D.

Abbreviated terms

CAD	computer-aided design
CMS	coordinate measuring systems (plural CMSs)
CT	X-ray computed tomography
CTE	linear coefficient of thermal expansion
GPS	geometrical product specification(s)
MPE	maximum permissible error (plural MPEs), see VIM
VIM	International Vocabulary of Metrology (see 2)

5 Requirements for metrological characteristics

5.1 Specification requirements

It is the manufacturer's responsibility to provide a detailed specification of the MPE values of the metrological characteristics over all rated conditions, for all specified hardware configurations (Annex A) and for all specified scanning modes (Annex B). The full specification also covers the requirements mentioned in 5.2 – 5.8. The manufacturer specifies the MPEs of the metrological characteristics in such a way that they are maintained throughout the entire measurement volume and under all rated measurement and operating conditions. To this end, the manufacturer shall describe the shape of the measurement volume, (e.g. diameter and height). The specification of the measurement volumes shall fully describe the unique configuration of the system geometry (e.g. the object and detector positions relative to the source). When declaring MPEs, the manufacturer shall also state relevant conditions, e.g., the maximum penetration length $L_{p,max}$.

This document considers two types of metrological characteristics: (1) those assessed without pre-knowledge and (2) those assessed with pre-knowledge (indicated by the 'PreK' or 'CAD' test qualifier). The differences between the cases are covered in 5.8. The actual measurement process is the same in both cases; hence, for the sake of brevity, only the case without pre-knowledge is described in 6, 7, 8 and all Annexes.

This document requires that the performance of a CT-based CMS be specified using all, not a subset, of the mandatory metrological characteristics (see 6.1). Thus, a set of all mandatory metrological characteristics can be specified either with pre-knowledge (indicated by the 'PreK' test qualifier for all of them or the 'CAD' test qualifier for all of them) or without pre-knowledge. It is also possible to specify more than one complete sets of mandatory specifications covering both cases (with and without pre-knowledge). The mandatory specifications can be supplemented with optional specifications (see Table D.1 and Annex D).

The values of the MPEs for any metrological characteristics may be stated by the manufacturer as a function of the measured length L – if applicable – and of the total penetrated length through matter L_p. In all cases, the specification shall be complied with across the CMS's entire measurement range and under all rated measurement and operating conditions. If the specification is provided by means

of a formula, the formula shall provide a valid specification value for all specified measurement and operating conditions.

NOTE 1 The manufacturer is not required to provide the above formula in a specific format. Examples of possible formulas include (but are not limited to) a linear statement $A + B \cdot L + C \cdot L_p$, with constants A, B, C, or alternatively one with only a constant value A.

If technically required, the manufacturer can specify the MPEs as a function of further parameters, e.g.,

- Source to detector distance (for a system with this degree of freedom)
- Measurement volume
- temperature

The maximum penetration length $L_{p,max}(j)$ can be specified as a constant for each material class j. It can also be expressed as a function of other parameters, e.g., the measurement volume.

NOTE 2 A further consequence of the change of $L_{p,max}(j)$ with the size of the measurement volume could be a change of the measurement parameters (e.g. X-ray tube voltage, prefiltering and X-ray tube current) depending on the size of the measurement volume.

The specification shall include all system settings and measurement parameters to allow testing of the performance of a CT-based CMS. Further information on the system under test such as the software version(s) should also be included. This specification shall be made for measurements of reference standards measured with air as a surrounding medium. If the specification is made for other surrounding media, this shall be clearly stated by the manufacturer. When the specification is at a single point or over a range for a given parameter, the MPE only applies at the specified point or range. Metrological characteristics beyond those mandated in this document can be specified by mutual agreement. For metrological characteristics that can have positive or negative values, the MPE value shall limit the absolute value of the respective metrological characteristic.

The manufacturer may restrict the validity of specified MPEs, e.g., for the following properties:

— The reference standard's material class

— The maximum penetration length for a specific material class $L_{p,max}(j)$

— The measurement volume V (e.g. diameter, height) and the associated magnification M

NOTE 3 Depending on the scanning mode (Annex B) the shape of the measurement volume can differ from the standard case of a cylinder.

— Environmental conditions (temperature, temperature gradients, etc.)

— Other adjustable parameters that are accessible to the user during normal measurement, e.g., the use of artefact correction methods (error correction techniques, i.e. data filtering applied to any step of the CT data processing to overcome specific imaging or measurement errors), mathematical and physical filters, additional sensors to aid in artefact (see 3) correction (i.e. a further physical sensor designed to enable the use of a specific artefact correction technique to enhance the quality of the CT measurement), X-ray voltage, measurement time, point density, etc.

If technically feasible and applicable, the manufacturer shall specify measurement volumes V_1 and V_2, where V_2 corresponds to the full volume, i.e. the maximum measurement volume over which the CMS can be tested and V_1 sets a lower limit for the measurement volume to be used in testing. The manufacturer shall specify at least one metrological characteristic set ($P_{Form.Sph.All.j::CT,MPE}$, $P_{Form.Sph.D95\%.j::CT,MPE}$, $P_{Size.Sph.All.j::CT,MPE}$ and $E_{Vol.j::CT}$). If only one metrological characteristic set is provided, these MPEs shall be valid throughout the range between measurement volumes V_1 and V_2. If more than one metrological characteristic set is stated and the CMS is qualified for measurements which use measurement volumes between V_1 and V_2, the manufacturer shall provide a statement describing which metrological characteristic set is valid for any measurement volumes between V_1 and V_2.

Depending on the CMS design, the kinematic system and the mode of operation, measurement volumes of identical size may have different metrological properties (i.e. different MPE values). The manufacturer shall clearly describe these conditions.

It is recommended that the two specified minimum and maximum measurement volumes V_1 and V_2 cover as much of the range of magnifications as possible to avoid restricted metrological characteristics and disparities between the specified and intended use of a CMS.

Optionally, the manufacturer may provide a statement for the maximum and minimum possible measurement volume V_{max} and V_{min}, respectively; here, neither limit is designed for specified measurements as a CMS. If stated, V_{max} and V_{min} are provided for information only.

NOTE 3 By definition $V_{min} \leq V_1 < V_2 \leq V_{max}$

NOTE 4 Specifications according to this document (i.e. MPE values) exist only for the interval of measurement volumes $[V_1, V_2]$ attributed to specifications.

NOTE 5 $P_{Size.Sph.1x25.j::CT}$, $P_{Size.Sph.All.j::CT}$, $P_{Size.Sph.D95\%.j::CT}$, $E_{Vol.j::CT}$, $E_{Bi.j::CT}$ and $E_{Bi.shrt.j::CT}$ can have positive or negative values, whereas $P_{Form.Sph.1x25.j::CT}$ and $P_{Form.Sph.D95\%.j::CT}$,$P_{Form.Sph.All.j::CT}$ are always positive by definition.

5.2 Environmental conditions

Limits for environmental conditions at the installation site shall be specified by:

- the manufacturer, for acceptance tests;
- the user, for interim checks or reverification tests.

The user is responsible for providing the correct environment for housing the CMS throughout testing. If the environment does not meet the requirement set for the specified metrological characteristics, MPEs cannot be verified.

5.3 Operating conditions

When conducting the tests in this document, the CMS shall be operated using the procedures and software (including the correct version) in the manufacturer's operating manual(s) and the manufacturer's specifications that correspond to the metrological characteristics. The rated operating conditions (i.e., the operating condition for which the MPE is claimed to be valid) shall be specified by the manufacturer in the relevant operating manual(s) in combination with the respective data sheet(s). Specific areas in the manufacturer's manuals to be adhered to may include:

a) limits for environmental conditions (5.2)

b) use of the software, including software version

c) location, type, number of thermal sensors

d) CMS system start-up/warm-up cycles, including X-ray source and X-ray focus conditioning

e) thermal stability of the whole CMS including X-ray source, X-ray detector and mechanical axes before system qualification and/or testing

f) system qualification

NOTE The system qualification is a set-up process which may be required to prepare a CMS for performing dimensional measurements.

The rated operating conditions shall include the hardware configuration (see Annex A) and the scanning mode applied (see Annex B). The manufacturer shall clearly indicate the measurement volume for all combinations of axis movements allowed. For systems that have a theoretically infinite length in one axis (described in Annex A), the manufacturer may specify a limit length parallel to this axis to