INTERNATIONAL STANDARD

ISO 15708-4

First edition
2017-02

Non-destructive testing — Radiation methods for computed tomography —

Part 4: Qualification

Essais non destructifs — Méthodes par rayonnements pour la tomographie informatisée —

Partie 4: Qualification

Reference number
ISO 15708-4:2017(E)

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Contents

Page

Foreword

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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 World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html

This document was prepared by the European Committee for Standardization (CEN) (as EN 16016-4) and was adopted, under a special "fast-track procedure", by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 5, *Radiographic testing*, in parallel with its approval by the national bodies of ISO.

It takes into consideration developments in computed tomography (CT) and computational power over the preceding decade.

A list of all parts in the ISO 15708 series can be found on the ISO website.

Non-destructive testing — Radiation methods for computed tomography —

Part 4: Qualification

1 Scope

This document specifies guidelines for the qualification of the performance of a CT system with respect to various inspection tasks.

It is applicable to *industrial* imaging (i.e. non-medical applications) and gives a consistent set of CT performance parameter definitions, including how those performance parameters relate to CT system specifications.

This document deals with computed axial tomography and excludes other types of tomography such as translational tomography and tomosynthesis.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes 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 15708-2, *Non-destructive testing — Radiation methods for computed tomography — Part 2: Operation and interpretation*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15708-1 apply.

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

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

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

4 Qualification of the inspection

4.1 General

CT is used in industry both for defect testing and dimensional testing and measurement. Since CT does not directly provide measurement of desired quantities such as, for example, pore size or wall thickness, these quantities must be derived from the X-ray linear attenuation data represented by the CT grey values. The detectability of features and the degree of accuracy required depend on the inspection task, the specification of the available test equipment and the analysis and evaluation methods used. When determination of such quantities is required, a special task-specific qualification test of the CT system is required. The qualification measures are described in 4.2 and 4.3. The qualification should be carried out by trained personnel. The trained personnel shall be able to prove they have undergone training and qualification in digital industrial radiography or radioscopy.

4.2 Qualification of defect testing

4.2.1 General

Under test qualification, the suitability of the CT inspection technique for measuring a quantity to the required precision should be verified. The following steps described are typical of those for the successful verification of the suitability of CT for industrial applications.

4.2.2 Quality feature

Typical quantities to be measured are the sizes of pores, cavities, cracks, inclusions, contaminants as well as studies of the material distribution and the assembly and installation position of components. Because the test sample and the type, position and size of the features to be detected determine the properties of a CT system to be used, information such as the following should be known:

a) test object:
   1) dimensions;
   2) weight;
   3) materials;
   4) path length to be X-rayed in the material;

b) test feature:
   1) type;
   2) position;
   3) size;
   4) distribution, frequency;

c) feature detectability:
   1) limiting defect;
   2) limiting feature.

Since the feature detectability strongly influences the specification and therefore the cost of a CT system, special attention must be taken when defining the sensitivity of the tests required. If, due to missing information, no limiting values for features are defined, it is recommended that the best possible sensitivity is used for the specific method and CT system and the attained feature detectability is verified using, for example, destructive tests.

4.2.3 Feature detectability/test system/system parameterisation

The usability of the CT system and the selection of system parameters are determined by the requirements for feature detectability. Typical variables are:

a) spatial resolution:
   1) overall spatial resolution of the CT image;
   2) scan geometry;
   3) detector spatial resolution;

4) focal spot size of radiation source;

b) contrast resolution:

1) overall contrast resolution of the CT image;

2) detector settings;

3) tube voltage;

4) tube current;

c) reconstruction/visualization:

1) number of projections;

2) CT grey value dynamic range of the reconstruction or visualization;

3) CT image size in X, Y and Z axes.

CT system set-up and image quality parameters are described in ISO 15708-2:2016, 4.1 and 5.1.

4.2.4 Verification of suitability

4.2.4.1 General

A reliable statement on the defect detection sensitivity and the defect detectability of the CT system used in a test shall be made by stating the degree of accuracy of the test required (tolerance, degree of fluctuation). Several alternative procedures are described in the following.

4.2.4.2 Reference samples with natural defects

If a reference sample with a known defect is available, inspection of this sample is carried out and the detectability is stated after the test has been done.

If a reference sample with unquantified defects is available, inspection of this part is carried out and the defect detectability is stated using a counter-check, using, for example, a destructive test after the CT scan has been done.

4.2.4.3 Reference sample with synthetic defect

If the test feature can be simulated using a synthetic defect, for example, a hole, the defect detectability verification can take place similar to the previous section.

4.2.4.4 Reference sample without specifications

If no specifications are available for the reference sample status and a counter-check is not possible, the test is carried out using the system sensitivity. Sample structures like, for example, wall thicknesses and external dimensional measurements can be used for estimating the defect detectability. Alternatively, reference samples like, for example, wires or spheres of known dimensions can be used.

4.2.5 Consistency check

The CT scan requires several very complex process steps for which the error sources cannot always be excluded. After the scan, the following can be used to trace the possible error sources:

— reconstruction: size, CT slice positions, possible artefacts ;

— CT image scale;

— sinogram (CT grey value and curve progress) or CT projection sequence (comparison between projections, image quality of the projections, intensity changes);

— system status (error messages).

Where errors occur, either they shall be corrected or their causes shall be eliminated and the test repeated.

4.2.6 Documentation

In the qualification report, the relevant parameters and results of the qualification steps are to be described and presented. The CT images are to be archived for a period which is to be agreed with the end-user. The test parameters are to be archived so that an identical test procedure is possible in the case of recurrent test parts and features.

4.3 Qualification of dimensional testing

4.3.1 General

CT inspection provides information about the 3D structure of a sample from which surface and geometry data can be derived. Because these data are based on X-ray-physical absorption differences at the contour transitions, small differences in measured values may arise compared to classical tactile or optical measuring procedures. In the following sections, those CT scan parameters which influence the results will be described, together with those process steps which affect the accuracy of the results.

4.3.2 Test and measurement task

Dimensional measurement tasks include the measurement of single dimensions in the test object, wall thickness measurements, surface extraction, volume extraction or nominal-actual comparisons. The required measurement precision is to be defined for every task and if necessary for different parts of the sample.

4.3.3 Dimensional testing/test system/system parameterisation

The degree of accuracy attainable depends on the test object, the limitations of X-ray physics and the subsequent data handling. An initial estimation of the degree of accuracy of a CT-based dimensional measurement can take place with the following parameters:

a) spatial resolution in the test object:

   1) dimensions;

   2) geometric magnification, voxel size;

   3) detector resolution;

   4) focal spot;

b) X-ray penetration of test object:

   1) material;

   2) maximal wall thickness to be X-rayed;

   3) contrast resolution;

c) 3D component data:

   1) original CT image voxel size;

   2) extraction steps and quality;

3) further processing steps and quality;

4) registration method.

For this estimation, it must be noted that -physical X-ray effects (like scattered radiation and beam hardening) as well as artefacts due to the detector and reconstruction method can lead to strongly varying degrees of accuracy in different parts of the sample. For a known measuring point, the local-parameters should be used.

The inspection task is to be rejected if the set of requirements lie outside the capacity of X-ray technology or the CT system.

4.3.4 Degree of accuracy

4.3.4.1 General

In the following, the procedures are described which, depending on the measurement task, permit a statement to be made on the degree of accuracy attained. The methods described provide the overall degree of accuracy of the whole measurement chain.

4.3.4.2 Reference sample

For the measurement task a reference part is used, which is subjected to a standard counter-measurement technique, for example tactile or optical and if necessary destructive measurement methods. By comparing the measurement data, statements can be made on the degree of accuracy (which may vary in different parts of the sample). The degrees of accuracy achieved can be transferred to similar parts for the same CT system parameters and comparable test objects.

Typical specifications are:

a) reference dimensions;

b) information on counter-measurement procedures;

c) standard deviation of measurement errors for a reference data record.

4.3.4.3 Reference bodies

If a complete counter-measurement is not possible, a measurement of accessible sample geometries with comparable attenuation values to the reference sample can be drawn on for estimating the degree of accuracy. The use of reference bodies such as spheres and dumbbells also represents an option for estimating the degree of accuracy.

Typical specifications are:

a) reference dimensions;

b) information on counter-measurement procedures and on the different test zones within the sample;

c) standard deviation of the measurement error for a reference data record.

4.3.5 Consistency check

See 4.2.5.

4.3.6 Documentation

See 4.2.6.

5 Qualification of the CT system

5.1 General

The ability of a CT system to produce high quality, stable and reproducible results relies on the same performance from all the system components and their interactions. To ensure this in everyday operation, a regular system inspection is recommended according to defined criteria.

A distinction should be made between inspections carried out at short intervals (e.g. weekly) by means of an "overall performance" test and those done at longer intervals (e.g. annually) for a quality level description and possible changes of individual system components.

5.2 Integral overall system test

For regular system monitoring, the reference sample should be similar to those typically used in the CT system. The complete test cycle should be performed using similar system parameters to those used when inspecting using typical test samples.

For the evaluation of system quality, the current test results are compared with reference measurements. It is recommended that measurements of different object structures like, for example, material defects (pores, cracks), thinnest and thickest position on the reference block, wall thicknesses, etc. are specified as quality criteria.

If combined systems (two tubes and/or detectors) are used, several suitable reference blocks are to be used for the respective system combinations (e.g. micro-focus and mini-focus application).

The test results and system status which results from this are to be documented and archived.

If differences are found, further inspections are to be carried out to determine the cause (see also 5.3). The aforementioned inspections should be carried out after any repairs and other important interventions in the overall system and before further use of the system.

5.3 Checking the system components

5.3.1 General

The following system components, which could potentially be affected, are to be checked during the initial operation when changes are suspected (after repairs and in the case of a crash) and at regular intervals.

5.3.2 Manipulation system

The track and positioning precision of the axes are to be checked. Measurement instruments like those used for checking coordinate measurement machines (CMMs) can be used.

5.3.3 Image scale

Sets of high-precision spheres with a known spatial configuration (e.g. sphere bars, dumbbells) are recommended for inspecting the CT image scale (see Figure 1 of ISO 15708-2:2016). Such samples have the advantage that differences in the CT grey level threshold used do not affect the dimensional result obtained.

5.3.4 Beam axis perpendicularity

The perpendicularity of the beam axis to the detector can be checked using suitable test samples (e.g. tungsten wires or tips, spheres).

5.3.5 Tube focal spot

The tube focal spot position shall be checked using a suitable method, for example by ensuring that dimensions obtained from CT scans at different magnifications are compatible (within stated error limits).

5.3.6 Tube stability

The stability of the X-ray tube output can be checked by means of a dose rate measurement.

5.3.7 Detector

The dynamics of the detector can be checked using a comparison with the as-delivered condition e.g. by imaging a stepped reference block. It is recommended that the detector is regularly checked for pixel failures.

The detector stability can be checked using a time series of intensity measurements.

5.3.8 Reconstruction

In the case of reinstallation, the exchange of hardware components or updates, it is recommended that a known set of projections is input. The reconstruction result (CT grey values and voxel size) is to be evaluated against a previous reconstruction of these projections.

5.3.9 Visualization

In the case of reinstallation, the exchange of hardware components or updates, it is recommended that a known CT image is loaded. The visualization result and quantitative measurements of it are to be evaluated against a previous visualization of this CT image.

5.4 Documentation

The date and time of the system monitoring, the steps implemented and the achieved result are to be documented and archived for a period to be specified.

6 Example of CT system resolution evaluation methods

6.1 Pre-amble

The performance of a CT system is related to numerous criteria with lesser or greater influence depending on the type of object tested (low or high attenuation), the type of characterization performed (search for defects, densitometry, etc.). Another way of dealing with the problem is to be aware that the performance of a CT system is always the result of a compromise between various parameters such as:

— spatial resolution;

— density resolution;

— acquisition time.

These three parameters are interdependent. Attempting to improve one of these parameters will degrade one or both of the others. It thus seems pointless to try to evaluate the “absolute performance” of a CT system. Such an evaluation shall in any case be performed within the context of the parts tested.

Nevertheless, performance evaluation based on the quantification of spatial and density resolution is presented as an example. This method applies to most existing CT systems and the results will be useful for the majority of examinations performed.

This method does not attempt to provide a detection limit for CT systems evaluated, but to quantify performance to compare different installations, or monitor such performance over time. Such a method can also be used to optimize acquisition parameters for a given context (type of tested part, dose constraints and acquisition time).

Reference objects shall be adapted for particular installations, such as microfocus installations and high- energy systems. Generally, objects used for evaluation should be as close as possible in terms of the attenuation and size of the parts tested. If needed, more specific objects can be designed to better meet the desired criteria.

The following clauses describe the reference objects and a method implemented as part of a comparative system on several installations differing in design, manufacturing method and age.

The recommended method should be adapted according to the context of the examination. The guidelines for creating these objects are indicated in 6.3.

The measurements shown in the following clauses apply in theory to all situations.

6.2 Acquisition parameters

Since each CT system has its own image acquisition and reconstruction properties, it is important that a standardised resolution measurement be made for each system, using an optimal voltage, voxel size and angular increment (where possible).

6.3 Recommendations for creating reference objects

The recommended method uses two types of reference object:

— one for measuring spatial resolution, comprised of one part containing a row of calibrated holes, see Figure A.1 of ISO 15708-2:2016;

— the other for measuring density resolution, comprised of one part containing inserts, see Figure 1.

Since all measurements are relative to the assumed properties of the reference objects, great care should be taken when defining and creating them.

The reference objects shall meet certain requirements to ensure optimum measurement conditions. A cylindrical geometry is chosen to avoid artefacts due to angular effects (edge artefact in accordance with ISO 15708-2:2016).

In order to measure density resolution, the inserts shall have a linear attenuation coefficient close to that of the material comprising the matrix, in order to avoid artefacts known as “edge effects” (according to ISO 15708-2:2016). The differences in attenuation between inserts shall remain low to ensure greater sensitivity in the measurement. Proper beam hardening correction shall be applied during reconstruction of the CT image. Moreover, to ensure applicability, the material of the reference objects shall be chemically similar and of a similar density to the test samples. This is because a CT image measures the X-ray linear attenuation coefficient which is related to, but not directly proportional to, the material density.

The materials making up the matrix and inserts shall be as homogeneous as possible; variations in density shall in any case be at least less by a factor of 10 than the expected precision of the CT system. The size shall be sufficient to allow an averaged measure on a ROI (region of interest) with several tens of pixels square.

When measuring spatial resolution, calibrated artificial defects are necessary. The precision of machining is generally much less than the desired spatial resolution, which creates certain manufacturing problems for reference parts dedicated for micro-focus systems. If high precision cannot be obtained when creating the part, such precision shall be obtained by a posteriori and precise measurement of the machining performed.

