BS ISO 15708-3:2017

BSI Standards Publication

Non-destructive testing — Radiation methods for computed tomography

Part 3: Operation and interpretation

National foreword

This British Standard is the UK implementation of ISO 15708-3:2017.

The UK participation in its preparation was entrusted to Technical Committee WEE/46, Non-destructive testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

Published by BSI Standards Limited 2017

ISBN 978 0 580 95776 5

ICS 19.100

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 March 2017.

Amendments/corrigenda issued since publication

Date	Text affected

INTERNATIONAL STANDARD

ISO 15708-3

First edition
2017-02

Non-destructive testing — Radiation methods for computed tomography —

Part 3:
Operation and interpretation

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

Partie 3: Fonctionnement et interprétation

Reference number
ISO 15708-3:2017(E)

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

Contents

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 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 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 16016-3) 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 ISO member bodies.

This first edition of ISO 15708-3 cancels and replaces ISO 15708-2:2002, of which it forms the subject of a technical revision. 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 3:
Operation and interpretation

1 Scope

This document presents an outline of the operation of a computed tomography (CT) system and the interpretation of results with the aim of providing the operator with technical information to enable the selection of suitable parameters.

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 15708-1:2017, *Non-destructive testing — Radiation methods for computed tomography — Part 1: Terminology*

ISO 15708-2:2017, *Non-destructive testing — Radiation methods for computed tomography — Part 2: Principle, equipment and samples*

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 Operational procedure

4.1 General

For target-oriented computer tomography (CT) inspection procedures, the test and measurement tasks are defined in advance with regard to the size and type of features/defects to be verified; for example, through the specification of appropriate acceptance levels and geometry deviations. In the following, the process steps of a CT application are described and information on its implementation provided.

4.2 CT system set-up

4.2.1 General

The CT system set-up is oriented towards the requirements for the given task. The required spatial resolution (taking into account the tube focal spot size), contrast resolution, voxel size and the CT image quality can be derived from these requirements. The quality of the CT image is determined by different parameters, which under certain circumstances counteract each other.

In the following, system parameters are described and information is provided on setting up a CT system for inspection. Due to the interactions of the different system parameters, it may be necessary to run through the set-up steps several times in order to acquire optimal data.

The optimal energy is that which gives the best signal-to-noise ratio and not necessarily that which gives the clearest radiograph (the dependency of the detector efficiency on the energy is to be taken into account). However, in order to differentiate between materials of different chemical composition it may be necessary to adjust the accelerating voltage to maximise the difference in their linear attenuation coefficients.

4.2.2 Geometry

The source-detector and source-object distances and thus also the beam angle used should be specified. In order to achieve high resolutions, the projection can be magnified onto the detector. The magnification is equal to the ratio of the source-detector distance to the source-object distance. Increasing source-detector distance leads to a reduced intensity at the detector and thus to a reduced signal to noise ratio. Accordingly, this also applies when using detectors with improved detector resolution, which can result in a reduction of the signal-to-noise ratio due to the reduced intensity per pixel. In general, for this reason, minimisation of the source-object distance is to be preferred.

In order to obtain high beam intensity at the detector, the source-detector distance should be selected so that it is as small as possible taking into account the required resolution so that the beam cone still fully illuminates the detector. In the case of 3D-CT, the (in general vertical) total cone beam angle measured parallel to the rotation axis should typically be less than 15°, but this is specimen dependant, in order to minimise reconstruction-determined (Feldkamp) distortions of the 3D model. In addition, these restrictions do not apply for the perpendicular (in general horizontal) beam angle. For a higher geometric magnification, the object must be positioned as near as possible to the source, taking into consideration the limit on sharpness imposed by focal spot size. The rotation of the object must take place at at least 180 °plus beam angle of the X-ray beam, whereby an improved data quality is the result of an increasing number of angular increments. For this reason, the object is typically turned through 360 °. Ideally, the number of angular increments should be at least $\pi/2$ × matrix size (uneven number of projections per 360°) where the matrix size is the number of voxels across the sample diameter or the largest dimension. For more information, refer to 5.5.

The number of projections should be > π × matrix size for best reconstruction quality (even or uneven number of projections per 360°).

In order to obtain as complete information as possible on the specimen, the requirement in general for a CT is that the object (or the interesting section of the object) is completely mapped in each projection on the detector. For large components that exceed the beam cone, a so-called measurement range extension is used. This measurement range extension is accomplished by laterally displacing either the object or the detector, recording the projection data in sequential measurements, and finally concatenating (joining) them. Under certain circumstances, it is also possible to only scan a part of the object (region-of-interest CT), which may lead to a restricted data quality in the form of so-called truncations.

A possible deviation of the recording geometry (offset between the projected axis of rotation and the centre line of the image) must be corrected for in order to obtain a reconstruction which is as precise as possible. This can be achieved by careful realignment of the system or be corrected using software.

4.2.3 X-ray source

At the X-ray source, the maximum beam energy and tube current are to be set such that sufficient penetration of the test object and tube power with a sufficiently small focal spot are ensured. The required voltage shall be determined by the maximum path length in the material to be X-rayed in accordance with ISO 15708-2:2017, 8.2. For the best measurement results, an attenuation ratio of approx. 1:10 should be used. That is the grey level through the sample should be about 10 % of the white level (both measured with respect to the dark level). The optimal range can be achieved through the use of pre-filters. It should be noted that every pre-filter reduces the intensity. Pre-filters have the additional advantage of reducing beam hardening, though further improvements can be made with software correction.

4.2.4 Detector

The following detector settings need to be set appropriately for the sample being scanned:

- exposure time (frame rate);
- number of integrations per projection;
- digitisation gain and offset;
- binning.

If necessary, corrections for offset, gain and bad pixels (which may depend on X-ray settings) should be applied.

The individual CT projection is determined by the detector properties: its geometric resolution, its sensitivity, dynamics and noise. The gain and exposure time can be adjusted together with the radiation intensity of the source so that the maximum digitised intensity does not exceed 90 % of the saturation level.

To reduce scattered radiation, a thin filter, grid or lamellae can be used directly in front of the detector (intermediate-filtering).

The ideal acquisition time is dependent on the required quality of the CT image and it is often limited by the time available for inspection.

4.3 Reconstruction parameters

The volumetric region to be reconstructed, the size of the CT image (in terms of voxels) as well as its dynamic range (which should take into account the detector dynamic range) shall be specified. In order to achieve sufficient CT image quality, settings for the reconstruction algorithm or corrections should be optimised.

The volumetric region is defined by the number of voxels along the X, Y and Z axes.

4.4 Visualization

Using volume visualisation, the CT image can be presented as a 3D object. Individual grey values can be assigned any colour and opacity values to highlight or hide materials with different X-ray densities. Zooming, scrolling, setting contrast, brightness, colour and lighting facilitate an optimal presentation of the CT image. In addition, it is possible to place user-defined sectional planes through the object in order to examine the internal structure, or to interactively visualise the CT image, for example by rotating and moving it as a 3D object. Image processing can be applied to CT images to improve feature recognition.

It may not be possible to load the whole CT image at full resolution into memory at once.

4.5 Analysis and interpretation of CT images

4.5.1 General

Typical features for inspection are pores, cavities, cracks, inclusions, impurities or inhomogeneous material distributions.

Typical measurement tasks are obtaining dimensional properties (such as length or wall thickness) or calculating object morphology.

4.5.2 Feature testing/defect testing

Features in the sample generally give rise to changes in CT grey level within the CT image. Analysis of CT images is performed by qualified personnel using software. A suitable contrast range or an automatic or manual calibration is used. The position, CT grey value and dimensions of features can be determined. Several tools are available for this, including manual ones or automatic tools such as strobe lines or gauges that engage at grey value thresholds or edges. For examining the structure and location of assembled components, a qualitative comparison of CT images without determination of the dimensions can suffice.

For an automatic determination using visualisation software tools (for example fault analyses), a calibration via the specification of a grey value range is, in general, required for the sample material to be measured. The specification of the grey levels can be done manually using histograms or in an interactive manner.

The detectability of features depends on the size of the feature relative to the geometric resolution and the contrast resolution compared with the contrast difference of the feature from the base material, as well as the quality of the image (signal to noise ratio, etc.) and any possible interference effects between adjacent voxels (partial volume effect). For the detectability of singular pores, cavities or cracks, their minimum extent should typically be 2 to 3 times the demagnified pixel size (at the position of the sample).

4.5.3 Dimensional testing

4.5.3.1 General

Depending on the task, there are various methods currently in use for determining geometric features. Point-to-point distances can be manually determined in the CT slices or more complex features can be extracted with the help of analysis software.

The measurement of the geometric properties of an object using CT is an indirect procedure, in which the dimensional measurement takes place in or is derived from CT images. For this reason, in order to facilitate precise measurements, an accurate knowledge of two important variables is necessary:

- the precise image scale or voxel size and
- the boundary surface of two materials, for example the component surface (material-to-air transition), which can be determined via a CT grey value threshold in the CT image.

4.5.3.2 Determination of precise image scale

The precise image scale or voxel size must be determined through the measurement of a suitable calibration standard (together with the measurement object and directly before/after the object inspection) or using a reference geometry at the object. For this, the voxel size or magnification, M, specified by the CT system is compared with the actual available and precisely determined (using the reference body/geometry) voxel size or magnification M*. Thus, for example, the exact voxel size can be determined with high precision via measurements without the disturbing influence of other variables (for example, the precise position of the component surface (grey value threshold) in the CT image) for the centre distances of a test piece (e.g. dumbbell, see Figure 1). In this procedure, it must be taken into account that the CT grey values of the test item can, under certain circumstances, be influenced by the accompanying reference bodies (for example, through changes to the contrast ratios, interferences and artefacts). Using the actual voxel sizes determined in this way, the visualisation software can be correspondingly scaled/corrected as regards the voxel size specified by the system.

Figure 1 — Reference objects (dumbbell)

4.5.3.3 Threshold value determination

In order to be able to carry out dimensional measurements, the component surface or material contact surface must be determined in the CT image. The component surface is generally derived from the transition from solid object to surrounding air. The boundary surface is defined via a threshold value and is thus dependent on the materials and the X-ray settings. This threshold may be specified globally for the entire CT image as an average grey value of, for example, the material and air. This is sometimes known as the “iso50 threshold”. A global threshold value or calibration using the iso50 method is suitable for many measurement tasks on objects made from homogeneous materials.

A global threshold is not suitable for objects made from several materials. In these cases, different thresholds should be used according to the materials either side of the boundary. Even in the case of objects made from homogeneous materials, beam hardening, scattering and other artefacts can result in local dimming or lightening in the CT image which would distort the measurement results. The grey value threshold, for example, for surfaces in the inside of the component thus frequently differs from that for surfaces on the outside of the component. The threshold can, if necessary, be determined locally from grey levels either side of the boundary. A determination of the overall component surface via locally determined threshold values, while more time consuming, is more tolerant towards contrast variations and artefact influences.

4.5.3.4 Adjustment of geometrically primitive bodies

In addition to simple point-to-point operations (see 4.5.3), methods from coordinate measurement technology, such as reference geometry adjustment may be employed. In this connection, so-called geometric primitive bodies or reference elements (for example planes, cylinders, spheres or similar) are fitted, using software, to object contours of interest in the correspondingly calibrated data. At the reference elements, geometric features (for example, diameter, distances, angles, etc.) are determined directly or by combining reference elements. By fitting to the typically several thousand measurement points of the corresponding data, there is thus, due to the statistic averaging and reduction of the user influence, an often much higher precision than via the manual distance measurement of two points.

4.5.3.5 Generation of geometric data

So-called triangular models can be extracted from the voxels and calibrated grey value threshold. These models represent the calibrated threshold value-isosurface, i.e. the material surface in the form of linked triangles. The triangular model contains – as part of the extraction process precision (see below) – the geometry information on the object surface. It consists of only two types of information: the so-called vertices and the information as to which vertices belong to a triangle. The vertices are 3D points, which lie on the threshold value-isosurface. The quantity of all vertices is also designated a point cloud. It is initially the linking information, i.e. the information as to which three vertices in each case form a surface triangle, which defines the course of the object surface.

A standard format for data exchange is the so-called STL file format (ASCII or binary and dimensionless). Alternatively, the point cloud (vertices without triangle information) can be exported, whereby in general important information on adjacent vertices is lost and if necessary must subsequently be reproduced.

The geometric quality of the generated point cloud or triangular model depends entirely on the number and position of the vertices. Since only triangles are assumed between the vertices in the triangular model, detailed surface structures, contained in the voxels, between the individual vertices can, under certain circumstances, not be represented and are thus lost.

The extraction of a point cloud or a triangular model from the voxels corresponds to a scanning of the object surface. For further processing, the amount of data must in general be reduced. The quality or geometric precision of the triangular model depends on how good the triangle can reproduce the actual course of the material surface (e.g. chord error). With special software applications, a low-loss reduction of the number of triangles is aimed for.

For each of these process steps, the involved losses are to be taken into account for the subsequent steps. Due to the special process conditions, the quality of the dimensional data is to be checked for plausibility and significance.

4.5.3.6 Nominal-actual comparison

A dimensional CT application is the comparison of the recorded part (actual object) with the nominal geometry from the CAD (or other sources). After registering the CT coordinate system with the CAD coordinate system, there is the option, via the appropriate software, of comparing the geometric deviation of the CT-measured actual component with the CAD specification of the nominal geometry. The nominal-actual comparison can be carried out between the exported STL model or the point cloud and the CAD data or by directly comparing the voxels with the CAD data without previous STL or point cloud extraction.

4.5.3.7 Further processing of geometric data

CT can also be used for the non-destructive determination of geometric data (reverse engineering), e.g. of prototype parts or adjacent components.

CAD models are not based on triangular models, rather on geometric primitives (e.g. cylinder) and so-called free-form surfaces. For this reason, a further processing of the geometric data in CAD systems, for example, the engineering of the surface determined from the voxels in a CAD-established model, is required. With the appropriate software, triangular models can be transferred to CAD-compatible elements (so-called reverse engineering), whereby CT-examined objects, i.e. real geometries, can again be incorporated into the CAD process.

5 Requirements for acceptable results

5.1 Image quality parameters

5.1.1 Contrast

The quantity that is reconstructed in X-ray CT imaging is the linear attenuation coefficient, μ. It is measured in units of inverse length (e.g. mm^{-1}) and is approximately proportional to the electron density of the material. To be distinguishable, a feature shall have a linear attenuation coefficient, μ_f, sufficiently different from the linear attenuation coefficient of its background material, μ_b.

Linear attenuation coefficients are functions of the incident X-ray energy. For simplicity in these discussions, the X-rays used are assumed to have a single energy, E, or to be approximated by some mean energy, $\bar{E}$ if a spectrum of energy is used. If this is not known, a reasonable rule of thumb would be one third of the accelerating potential if the test object is weakly attenuating or 2/3 if the test object is strongly attenuating.

Figure 2 shows the functional energy dependence of the X-ray linear attenuation coefficients of two hypothetical materials, μ_b and μ_f. $\Delta\mu$ is the difference in attenuation for these two materials:

$$\Delta\mu = |\mu_b - \mu_f| \tag{1}$$

Contrast in CT has been defined historically as the percent difference of a feature from a background material.

$$\text{Contrast:} \quad \Delta\mu\ (\%) = \frac{|\mu_b - \mu_f|}{\mu_b} \times 100 \tag{2}$$

This definition for contrast assumes that the feature in question extends throughout the thickness of the CT slice. If the feature has thickness, h_f, but is imaged with a slice of larger thickness, h_s, the contrast is further reduced by the factor h_f / h_s (partial volume effect).

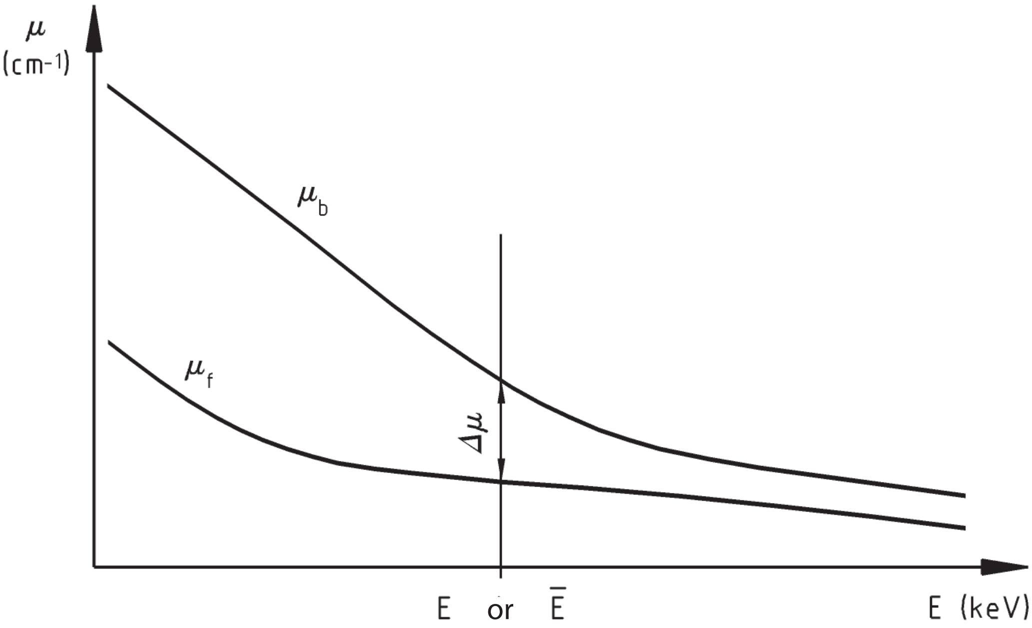
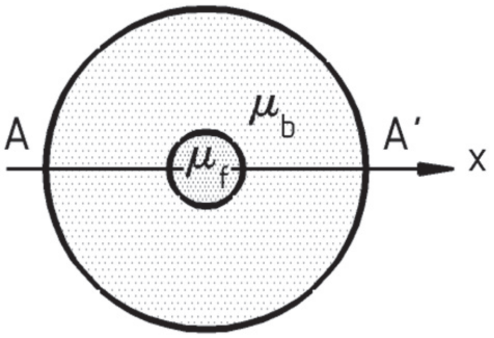


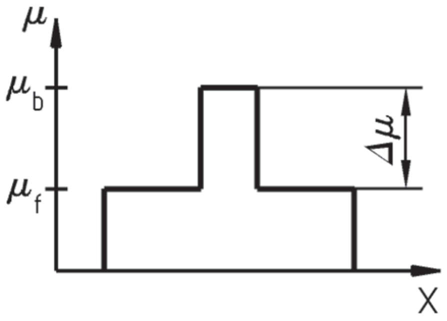
Figure 2 — $\Delta\mu$ as a function of X-ray energy

This difference $\Delta\mu$ and thus the contrast depends greatly on the X-ray energy, which is thus an important parameter. Choosing a low energy maximizes contrast but is detrimental to good detectability (degraded signal to noise ratio). The optimum trade-off clearly depends, to a great extent, on the specific application.

If the CT system did not introduce degradation, a profile through the centre of the object shown in Figure 3 a) (a feature centred in a background) would have the sharp form shown in Figure 3 b).



a) CT slice of an element whose attenuation coefficient is μ_f included in a background element whose attenuation coefficient is μ_b



b) Signal profile plot through the object in a) along the line A–A′

Figure 3 — Illustration of contrast

5.1.2 Noise

The number of photons produced per unit time varies because of the statistical nature of the radiation emission process. The variations have well-defined characteristics, which can be described by what is referred to mathematically as Poisson statistics. This ubiquitous radiographic problem of photon statistics is handled in CT by integrating (or counting) long enough to keep statistical noise to a diagnostically acceptable level. What constitutes an acceptable noise level is defined by the application and can vary widely.

The photon noise (or quantum noise) on the X-ray signal is characterized by the fact that the variance of the signal is equal to its mean (Poisson statistics).

It is customary to specify noise as the standard deviation, which is the square root of the variance. This means that if an average of N photons is detected per sampling period, the number recorded in any particular sampling period will be in the range of $N \pm \sqrt{N}$ approximately 68 % of the time.

There may be additional noise from the detector electronics and scattered radiation. In a detailed analysis, these contributions shall be included.

Noise is measured on a test phantom representative in terms of the tested object's size and attenuation (the test phantom can be the same cylinder used for measurement of the MTF, see 5.1.5). The test phantom must have a sufficiently extensive homogeneous area to provide satisfactory statistics.

Experimentally, the usual process for determining the standard deviation, σ, for a homogeneous area of a reconstructed image containing m pixels, each with some value μ_i, is to first find the mean value of the set of m pixels:

$$\bar{\mu} = \frac{1}{m}\sum_{i=1}^{m}\mu_i \tag{3}$$

and then compute σ, the standard deviation of the values of μ_i about the mean $\bar{\mu}$, as follows:

$$\tilde{A} = \sqrt{\frac{\sum_{i=1}^{m}(\mu_i - \bar{\mu})^2}{m-1}} \tag{4}$$

σ is not very sensitive to the number of pixels averaged if m is in the range of $25 \le m \le 100$. The noise in a reconstructed image does have a positional dependence, especially near the edges of an object, so extremely large regions shall not be used. The noise in CT images is not completely uncorrelated, but the effect on σ is small.

5.1.3 Signal to noise ratio

The signal-to-noise ratio (SNR) is given by:

$$\text{SNR} = \frac{\bar{\mu}}{\sigma} \tag{5}$$

The SNR depends on the level of the attenuation encountered and can vary according to the location of the area in the object or in the reconstruction diameter. The SNR increases with the X-ray dose: the higher the SNR, the better the image quality.

5.1.4 Contrast to noise ratio

Noise (σ) will increase the distribution of CT grey values (μ) in a material and may cause CT grey values in different materials (μ_f and μ_b) to overlap, see Figure 4.

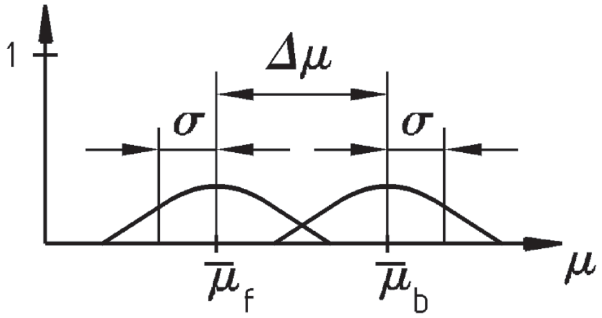


Figure 4 — CT grey value distribution in material and background

The contrast to noise ratio (CNR) indicates whether the attenuation difference between a feature and its background is greater than the background noise level. Typically, a CNR value of 3 represents a good confidence detectability.

$$\mathrm{CNR} = \frac{\left| \mu_\mathrm{f} - \mu_\mathrm{b} \right|}{\sigma_\mathrm{b}} \qquad (6)$$

Since CNR is a function of μ_b, it cannot be considered as an absolute property of the CT system.

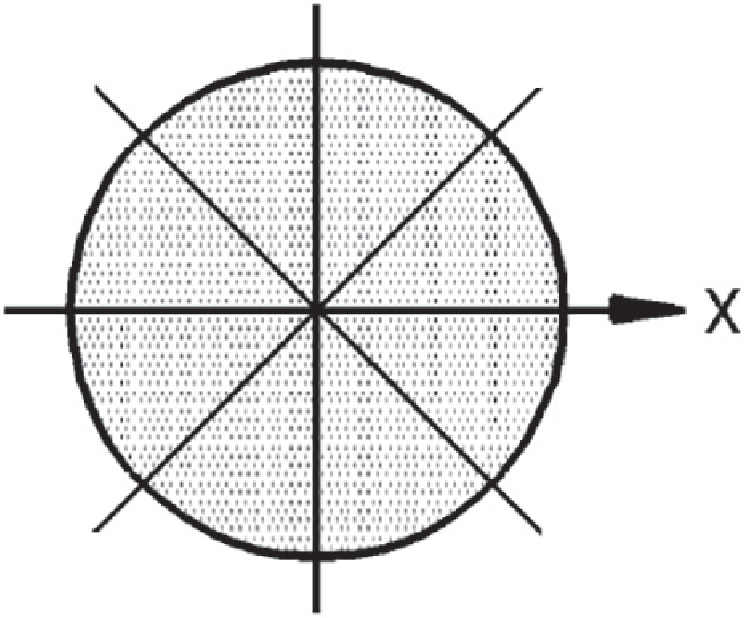
NOTE Contrast to noise ratio (CNR) is sometimes referred to as density resolution. It can only be related to material density with a proper calibration according to ISO 15708-4:2016, 6.4.4.

5.1.5 Spatial resolution

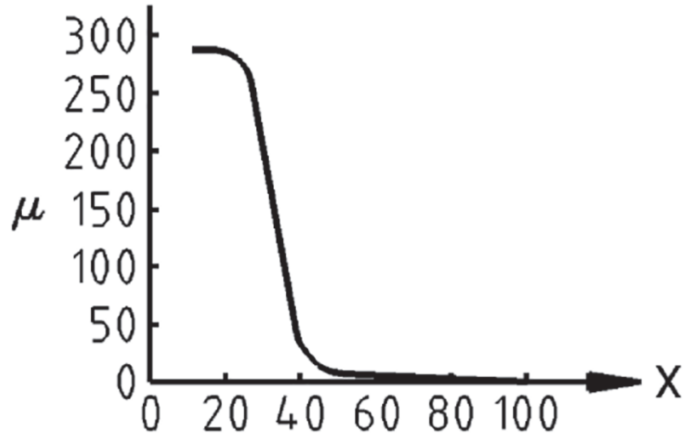
The standardised parameter to characterize the system spatial resolution is the concept of modulation-transfer function (MTF), which is the modulus of the one-dimensional Fourier transform of a Dirac profile convolved by the system's point spread function (PSF). The PSF is thus the response of the system to an ideal point object. The MTF describes the ability of the system to reproduce spatial frequencies. In general, low frequencies (large, homogeneous features) are reproduced more faithfully than high frequencies (small features). The MTF is not only a purely theoretical mathematical representation. It is used to predict and measure system performance, and compare different systems.

Figure 5 illustrates the experimental method of obtaining the MTF from the image of a simple cylinder. The use of a cylinder [see Figure 5 a)] is preferred because, once its centre of mass is determined, profiles through this point are perpendicular to the cylinder edge. Many profiles can be aligned and averaged to reduce system and quantum noise on the edge-response function (ERF) [see Figure 5 b)].

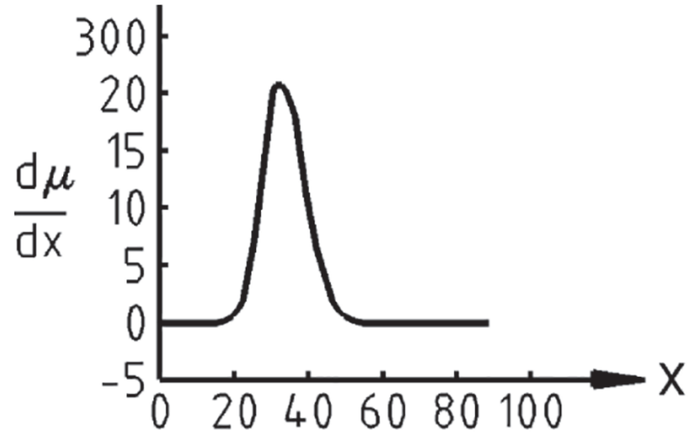
By convention, the height of the MTF is normalized to unity. It is plotted in spatial-frequency units, usually expressed in line pairs per millimetre (lp/mm). This procedure is easy to execute and not open to misinterpretation.



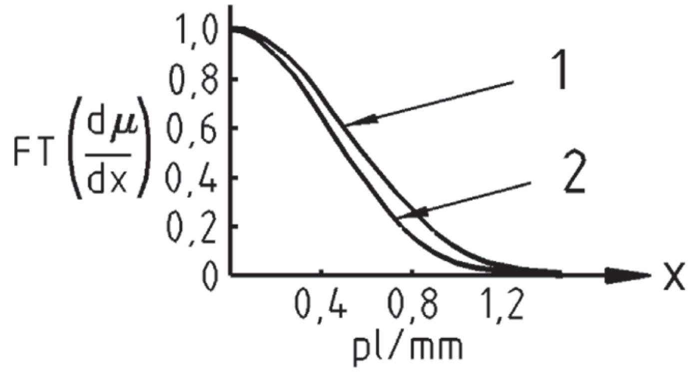
a) CT image of a cylinder



b) Profile along a diameter: edge response function (ERF)



c) Derivative of the ERF: line response function (LRF) or point spread function (PSF)



d) Modulus of the LRF Fourier transform: modulation transfer function (MTF)

Key

1	theoretical curve
2	experimental curve

Figure 5 — Method to obtain the modulation transfer function (MTF) from the image of homogeneous cylinder

A test phantom manufactured as a simple cylinder of the same material as the actual test object is recommended (to be representative of the attenuation level) for the measurements. A cylinder of same or comparable attenuation or size as the test has the advantage of serving double duty for the MTF and SNR measurements. However, it also limits the amount of knowledge that can be obtained about MTF variations within the CT reconstruction. A cylinder made of more attenuating material than the test object can be made much smaller than the reconstruction diameter and has the advantage of providing a measure of the modulation transfer function (MTF) as a function of position. In this case, a separate test phantom may be required to obtain representative results.

Line pair gauges may be used to directly confirm the MTF at discrete points. The measurement method using such dedicated test objects is detailed in Annex A.

5.2 Suitability of testing

The process steps/procedures, the features to be measured and the accuracy required are to be documented. The results are to be evaluated via comparison with the corresponding specifications on, for example, density resolution, "critical defect" detection or accuracy and uncertainty of the measurement of geometric features.

The suitability of testing is obtained if specifications are respected. Image quality parameters are selected depending on the application. For example, for obtaining best density resolution, SNR is to be optimised, whereas for dimensional measurements spatial resolution is to be optimised. For a limited time scan, it is not possible to optimise both of these at the same time.

5.3 CT examination interpretation and acceptance criteria

Interpretation can be manual, computer-assisted or completely automatic.

It is not practical to try to evaluate the "absolute performance" of a CT system. Such an evaluation shall always be performed within the context of the parts tested.

Therefore, any purchaser of a CT system shall agree acceptance criteria with the supplier at the time of purchase.

5.4 Records and reports

Table 1 covers the parameters that are useful to include in records and examination reports.

Table 1 — Parameters useful to record

Acquisition parameters	Reconstruction parameters
— Voltage or energy — Intensity or flow — Focal spot size and/or main collimator size — Acquisition geometry — Detector type and characteristics — Size of detector or size of backup collimator — Number of projections — Acquisition intervals — Acquisition fields — Integration time — Material and thickness of the filter — Format of acquired data — Operator	— Type of algorithm used — Name and version of software — Reconstruction size (in pixels or voxels) — Plane or volume reconstructed — Software filtering — Format of reconstructed data — Operator

5.5 Artefacts

5.5.1 General

An artefact is an artificial feature which appears on the CT image but does not correspond to a physical feature of the object. All imaging systems, whether CT or not, exhibit artefacts. Some of the artefacts are inherent in the physics and the mathematics of CT and cannot be eliminated, such as "edge effects" on the edges of areas with high attenuation. Others are due to hardware or software deficiencies in the design and can be attenuated by improved engineering. Examples of the latter type of artefact are due to scattered radiation and deviations in response between the detectors.

Artefacts occurring at the interfaces between differently attenuating materials are more subtle. There is often an overshoot or undershoot in the grey-level profile at such a boundary. This may lead to misinterpretation (false indications of defects or, more importantly, situations in which defects go undetected). The type and severity of artefacts are some of the factors that distinguish one CT system from another with otherwise identical specifications.

The purchaser and supplier of CT examination services shall understand the differences in these artefacts and how they will affect the integrity of the CT examination. For example, absolute material density measurements will be severely affected by uncompensated cupping effects, see 5.5.2, but the same artefact will probably not affect the detectability of radial cracks.

5.5.2 Beam hardening artefacts

Beam hardening is an effect encountered with polychromatic X-ray sources, such as X-ray tubes or linear accelerators (linacs). Such sources of Bremsstrahlung, as opposed to monoenergetic (i.e. isotopic) sources, produce a flux whose average radiation energy becomes progressively higher as it propagates through an object because the lower-energy photons are preferentially absorbed with respect to the more energetic ones. Since this filtered X-ray beam is more penetrating, it leads to an underestimate of the linear attenuation in the inside of the sample relative to that of the unfiltered beam nearer the edge of the sample. Such a reduction in attenuation inside the sample is also known as a "cupping effect" (see Figure 6). Although this effect can be partially controlled by conscious engineering choices, it is generally a significant problem and shall be corrected for at some stage in the reconstruction process.

A typical correction procedure consists in acquiring the signal of a step wedge covering a sufficient range of thicknesses made of the same material as the sample. Then, the grey-values in the projection data can be converted to true thickness values and a corrected slice is thus reconstructed. However, this procedure may not be valid in the case of a sample made of several materials.

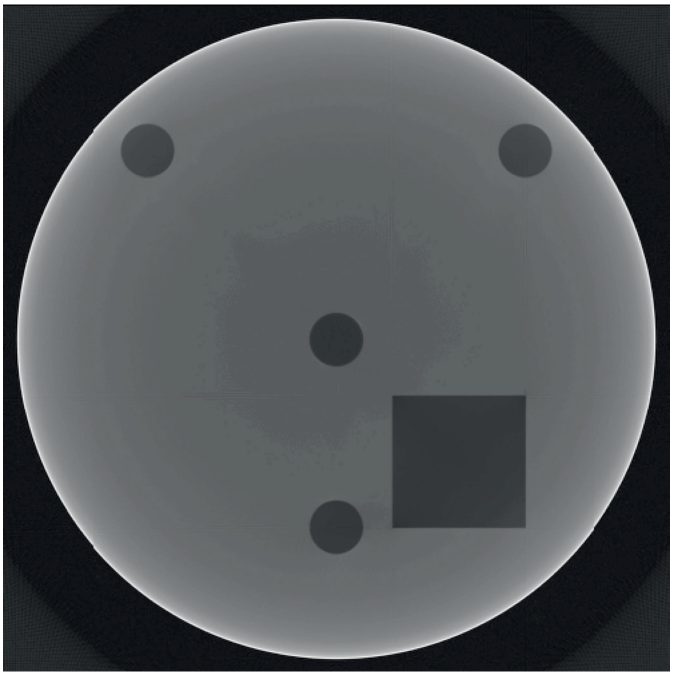


Figure 6 — Example of cupping effect[2]

5.5.3 Edge artefacts

Another source of difficulties is the finite width of the beam. A beam of X-rays is geometrically defined by the size of the focal spot of the X-ray source and the active area of each detector element. Each measurement represents a convolution of the desired line integral with the profile of the beam. In general, the width of the strip integrals is small enough that although some loss of spatial information occurs, no distracting artefacts are generated. The exception occurs when there are sharp changes in signal level. The error then becomes significant enough to produce artefacts in the reconstructed image which becomes manifest in the form of streaks between high-contrast edges in the image, see Figure 7. These edge artefacts are caused by the difference between the measured quantities and the requirements of the reconstruction process. What is measured is the logarithm of the line integral convolved with the profile of the beam. What the reconstruction process requires is the convolution of the beam profile with the logarithm of the line integral. These are not mathematically equivalent.

Unfortunately, edge artefacts cannot be eliminated by simply reducing the effective size of the focal spot or the detector apertures, or both, through judicious collimation. As the strip integrals are reduced to approximate line integrals better and to reduce susceptibility to edge artefacts, count rates become severely curtailed, which either leads to much noisier images or much longer CT scan times, or both. In practice, the focal spot size and the active area of each detector element in correspondence to the employed magnification are engineered to be as small as practicable, and if further reductions in edge-artefact content are required, these are handled in software. However, software corrections entail some type of deconvolution procedure to correct for the beam profile and are complicated by the fact that the intensity profile of the beam has a complex geometrical shape that varies along the path of the X-rays.

Edge artefacts that manifest themselves as streaks between high-contrast edges in the reconstructed image, can occur when there are sharp changes in signal level.

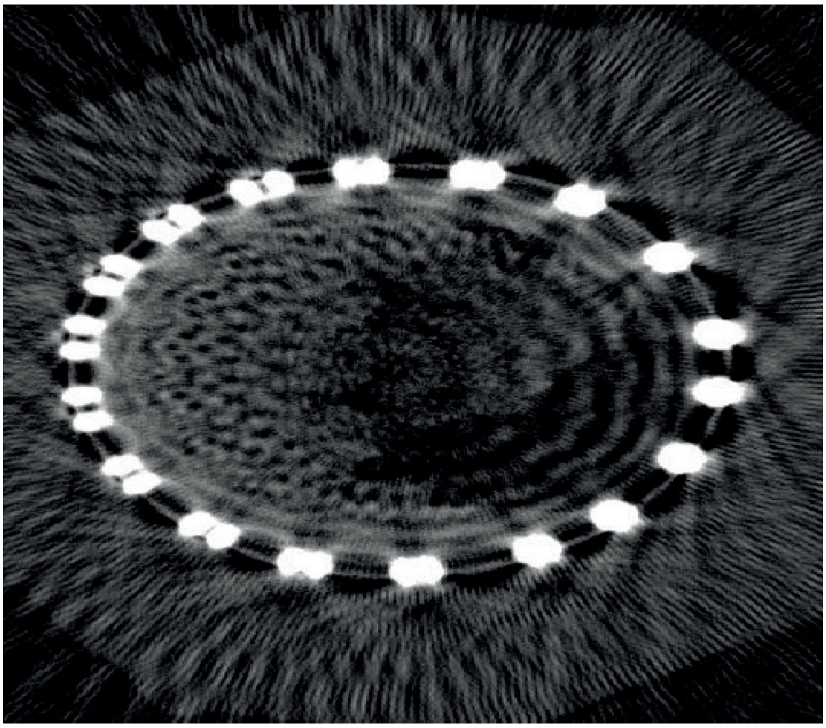


Figure 7 — Dark streaks between high-contrast edges due to edge artefacts[2]

5.5.4 Scattered radiation

Still another source of problems arises from the presence of scattered radiation. When multiple detector elements are used, there is always the chance that radiation removed from the incident flux by Compton interactions will be registered by another detector element. This scattered radiation, which increases with higher energies, cannot be easily distinguished from the true signal and therefore corrupts the measurements. This problem can be reduced, but not eliminated, through the use of proper collimation.

Electronic and mechanical nonlinearities and instabilities may result from corrigible engineering deficiencies or basic physical limitations of the individual components of the CT system. In some cases the problem can be corrected (or reduced) in software; in others it can be fixed only by re-engineering the offending subsystem. Considerable effort is required to keep these types of errors small compared to other less manageable sources of error, such as those discussed above.

5.5.5 Instabilities

Electronic and mechanical nonlinearities and instabilities also represent sources of inaccuracy. These may result from corrigible engineering deficiencies or basic physical limitations of the available components. The validity of the data is impacted in either case. In some cases, the problem can be corrected (or reduced) in software; in others, it can be fixed only by reengineering the offending subsystem. Because the bulk of existing information on this crucial topic is commercially sensitive and therefore proprietary, the literature is relatively sparse. All that can be said on these issues in this context is that considerable effort is required to keep these types of errors small compared to other less manageable sources of error, such as those discussed above.

5.5.6 Ring artefacts

Ring artefacts are systematic errors which are always connected to a gain error in the detector (faulty element in the sensor array, non-linearity of response, ageing of the detector or the like) or suboptimal calibration. Furthermore high spatial resolution enhances the development of ring artefacts. These artefacts appear in the reconstructed image as a number of concentric rings, which have their centres on the rotational axis of the CT system, see Figure 8. Reduction of ring artefacts is possible by appropriate calibration, by flat-field correction, which involves the generation of an “empty” image without the corresponding object or by post-processing methods.

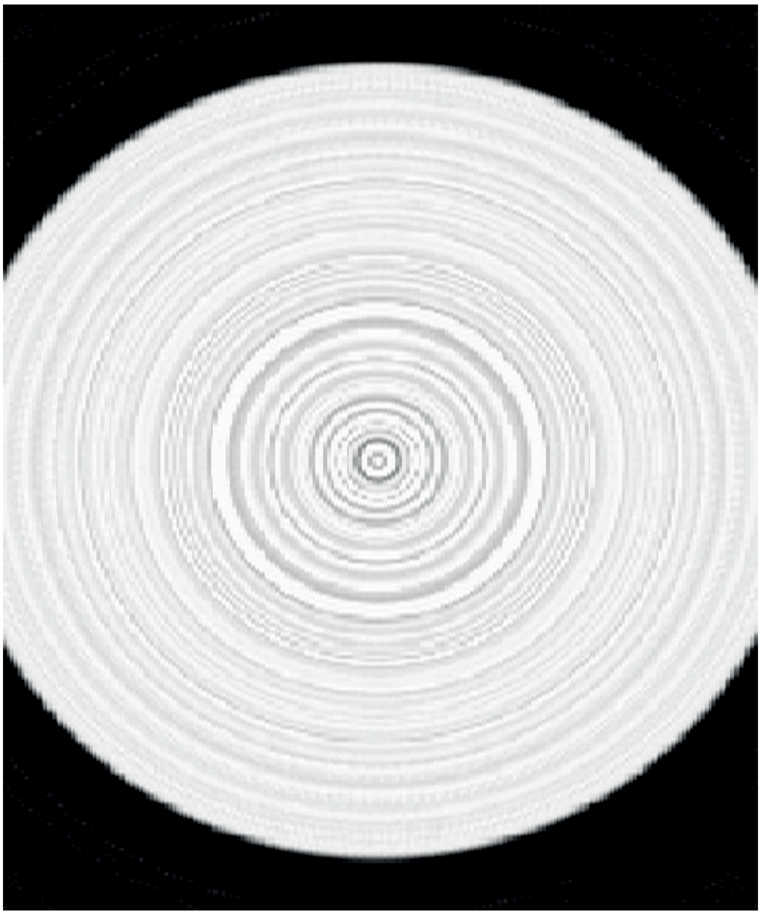


Figure 8 — Ring artefacts[2]

5.5.7 Centre of rotation error artefacts

Centre of rotation artefacts are systematic errors due to an error in the measurement of the inspection geometry. If the axis of rotation is not measured precisely then the projection images are not correctly projected back through the volume and a particular point-like feature in the projection images will not be reconstructed to a point in the CT volume, but rather a circular shape. The overall effect is to make slices perpendicular to the rotation axis doubled, while not affecting slices parallel to the rotation axis, see Figure 9.

Most acquisition software and/or reconstruction software should allow the user to determine the correct axis of rotation, or determine it automatically. Any tilt of the rotation axis relative to the vertical columns of pixels in the detector should be corrected by the reconstruction software.

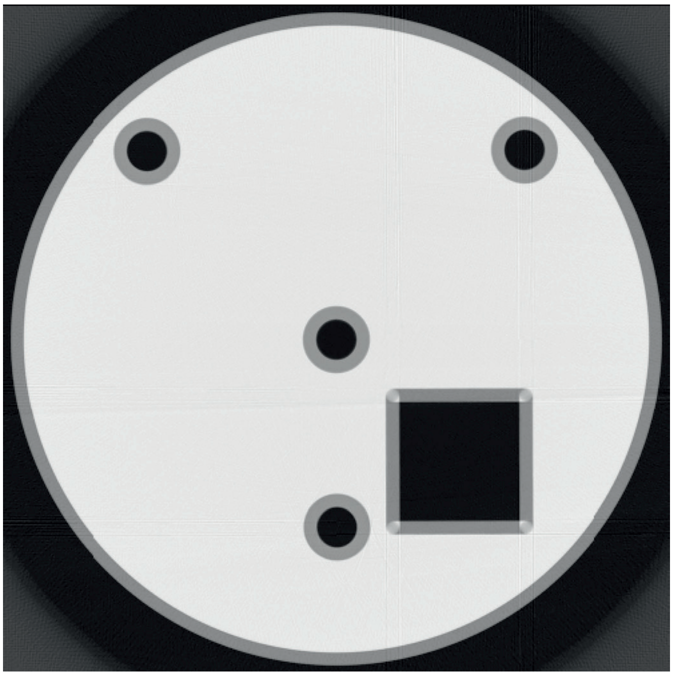


Figure 9 — Centre of rotation error artefacts[2]

5.5.8 Motion artefacts

Motion artefacts are caused by sample movement during the CT scan. Since such movement is generally only in one direction, the streak artefacts introduced tend to be orientated in one direction only. There will often be a doubling within the CT slices, but this will be asymmetric, and not symmetric as in the centre of rotation artefacts, see Figure 10.

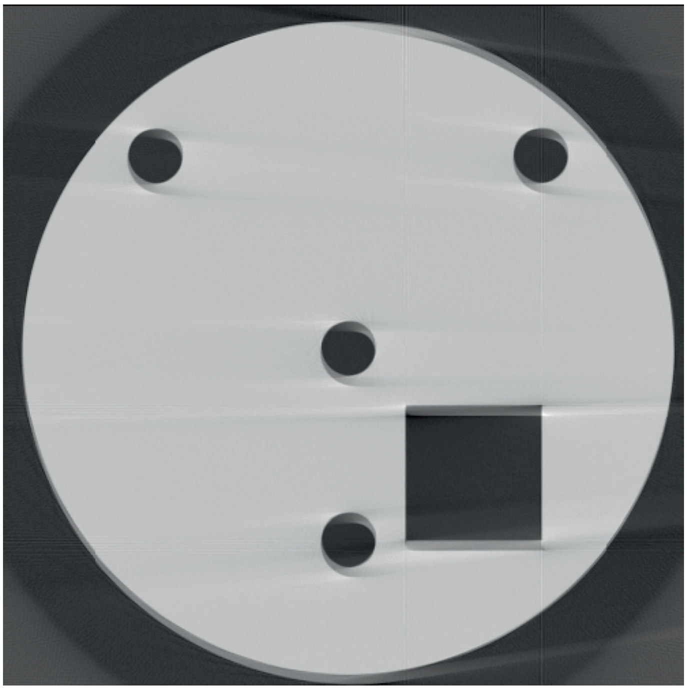


Figure 10 — Motion artefacts[2]

5.5.9 Artefacts due to an insufficient number of projections

If the number of projections in a CT scan is insufficient (the exact number of projections needed depends on the shape of the object), then radial streaks may appear in CT slices perpendicular to the rotation axis. The strength of these artefacts will diminish if more projections are included in the reconstruction. The strength of the artefact varies with the sample geometry and is stronger around angular components, see Figure 11.

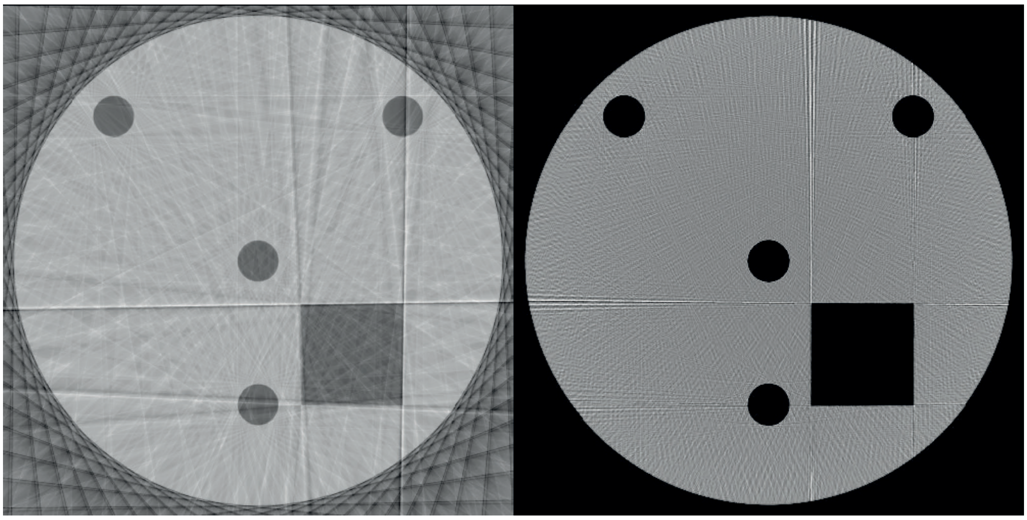


Figure 11 — Artefacts due to an insufficient number of projections[2]

5.5.10 Cone beam artefacts

Certain reconstruction algorithms, e.g. Feldkamp cone beam, assume that all parts of the sample are viewed from a set of angular positions perpendicular to the rotation axis. This is only true for the parts of the sample on the beam axis, and the slight deviations from perpendicularity for the rest of the sample may introduce so-called "cone beam artefacts", see Figure 12.

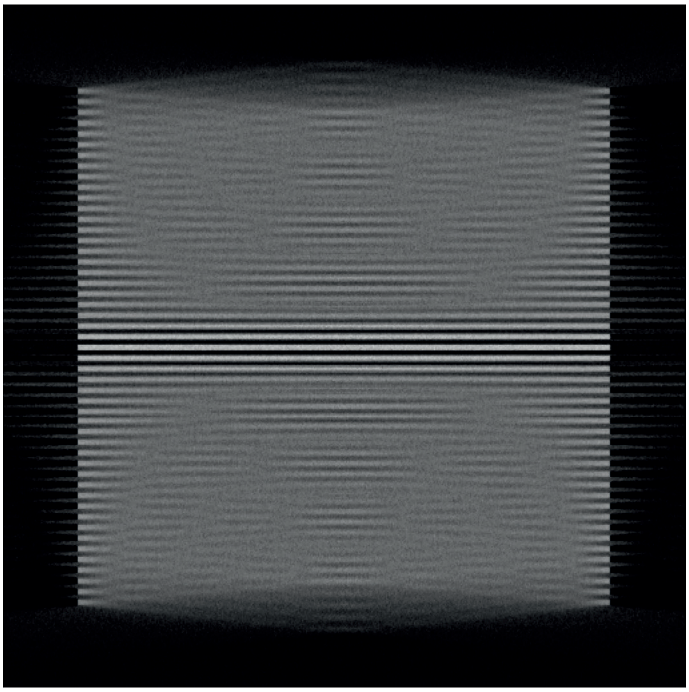


Figure 12 — Cone beam artefacts in a stack of discs[2]

Annex A
(informative)

Spatial resolution measurement using line pair gauges

A.1 Line pair gauges

The reference objects selected to develop the measurement method in the experimental case described are comprised of a 65 mm diameter cylinder in which a square section of 8 rows of 5 holes are machined, spaced at a distance equal to the length of their sides. These square sections vary from 0,4 mm × 0,4 mm to 2,5 mm × 2,5 mm (see Figure A.1).

The rows of holes were chosen by their similarity with the IQI generally used in traditional radiography, indicated by systems with line pairs. The correlations between the rows of calibrated holes and the line pairs per centimetre are shown in Table A.1

Table A.1 — Correlation between hole sizes and their equivalence in line pairs per centimetre

Row mm	**Equivalent line pairs/cm**
0,4 × 0,4	12,5
0,75 × 0,75	6,67
1 × 1	5
1,25 × 1,25	4
1,5 × 1,5	3,33
1,75 × 1,75	2,86
2 × 2	2,5
2,5 × 2,5	2

To meet the requirements of the different installations used in the comparison system, three materials with different attenuation were used to create these reference objects: plexiglass, an aluminium alloy and stainless steel. The three parts are shown in Figure A.1.

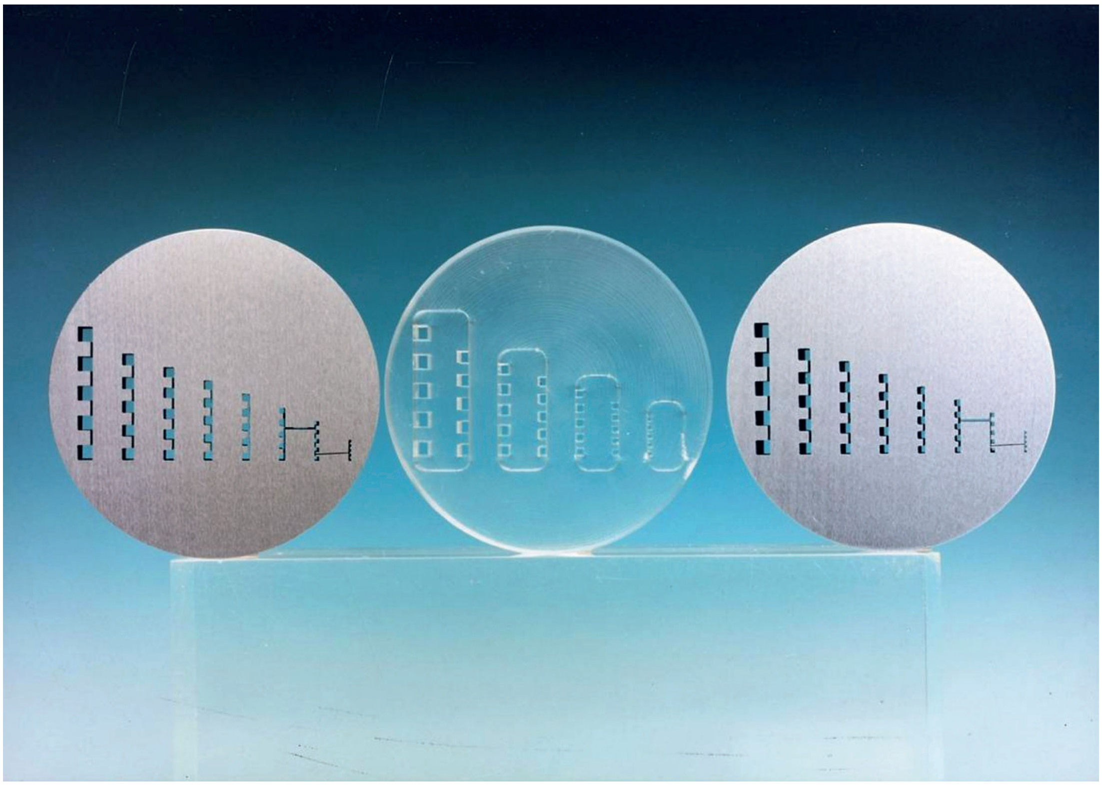
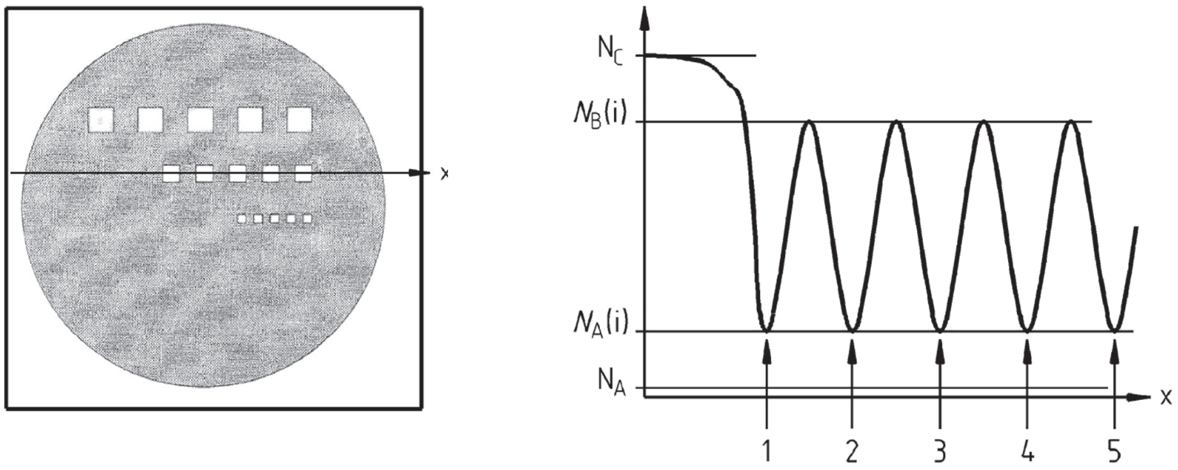


Figure A.1 — Example of reference objects for spatial resolution measurement made of different materials (from left to right respectively aluminium, plexiglass and steel)

These three parts machined according to the same principle are used as the reference. The choice of materials and the number of parts created are not limited. They can be chosen, complying with the principles defined in ISO 15708-2:2017, Clause 5, so as to specifically meet the requirements of the tests to be run.

A.2 Principle of measurement

The purpose of the measurement is to indicate simply the CT system response to the reference object particularities (described in Figure A.1 and Table A.1.) The determining factor for this measurement is taken as a coefficient R indicating the percentage of contrast as a function of resolution in line pairs per centimetre. The plot of R as a curve is a useful mean to compare several CT systems.



a) Scheme of the square holes in the cylinder **b) Signal profile along a line of constant spatial frequency**

Key

N_A	signal inside the holes;
N_B	signal between holes
N_C	material signal

Figure A.2 — Measurement principle of response factor using line pairs gauge

This response factor expressed in percentage is defined by the Equation (A.1):

$$R(i) = \frac{N_B(i) - N_A(i)}{N_C - N_A} \times 100 \tag{A.1}$$

where

$N_A(i)$ is the mean value of the CT grey values in the 5 holes in row i;

$N_B(i)$ is the mean value of the CT grey values between two holes in row i.

These two values are measured using a grey-level profile determined along the hole axis and unaveraged (see Figure A.2).

N_C is the mean value of the grey-level value of the material measured on a surface of at least 10 pixels square, located outside the reference part.

N_A is the mean value of the air grey value measured on an area of at least 10 pixels square, located at the centre of the reference part.

N_A(i), N_B(i), N_C and N_A are shown in Figure A.2. Note that the response factor can be positive or negative because different CT systems may have different grey-level dynamic ranges so that air can have a lower or higher value than a dense material.

To include statistical grey-level distribution in the measurements, a quantity denoted as $\frac{\Delta S}{3\sigma}$ is defined as follows:

$$\frac{\Delta S}{3\sigma}(i) = \frac{\left|N_{\mathrm{B}}(i) - N_{\mathrm{A}}(i)\right|}{3\sigma} \qquad \text{(A.2)}$$

where

σ is the standard deviation of the background material CT grey values measured over a surface of at least 10 pixels square (noise).

Bibliography

[1] ISO 15708-4:2016, *Non destructive testing — Radiation methods for computed tomography — Part 4: Qualification*

[2] DAVIS G. R., & ELLIOTT J. C. "*Artefacts in X-ray microtomography of materials.* Mater. Sci. Technol. 2006, **22** (9) pp. 1011–1018

ICS 19.100

Price based on 23 pages

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Copyright in BSI publications

All the content in BSI publications, including British Standards, is the property of and copyrighted by BSI or some person or entity that owns copyright in the information used (such as the international standardization bodies) and has formally licensed such information to BSI for commercial publication and use.

Save for the provisions below, you may not transfer, share or disseminate any portion of the standard to any other person. You may not adapt, distribute, commercially exploit, or publicly display the standard or any portion thereof in any manner whatsoever without BSI's prior written consent.

Storing and using standards

Standards purchased in soft copy format:

- A British Standard purchased in soft copy format is licensed to a sole named user for personal or internal company use only.
- The standard may be stored on more than 1 device provided that it is accessible by the sole named user only and that only 1 copy is accessed at any one time.
- A single paper copy may be printed for personal or internal company use only.

Standards purchased in hard copy format:

- A British Standard purchased in hard copy format is for personal or internal company use only.
- It may not be further reproduced – in any format – to create an additional copy. This includes scanning of the document.

If you need more than 1 copy of the document, or if you wish to share the document on an internal network, you can save money by choosing a subscription product (see 'Subscriptions').

Reproducing extracts

For permission to reproduce content from BSI publications contact the BSI Copyright & Licensing team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email subscriptions@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Useful Contacts

Customer Services
Tel: +44 345 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 345 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK