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Neporušitveno preskušanje - Sevalna metoda - Računalniška tomografija - 3. del: Delovanje in razlaga

Non destructive testing - Radiation Methods - Computed Tomography - Part 3: Operation and interpretation

Zerstörungsfreie Prüfung - Durchstrahlungsverfahren - Computertomographie - Teil 3: Durchführung und Auswertung

Essais non destructifs - Moyens utilisant les rayonnements - Tomographie informatisée - Partie 3: Fonctionnement et interprétation

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Non destructive testing - Radiation methods - Computed Tomography - Part 3: Operation and interpretation

Essais non destructifs - Méthodes par rayonnements - Tomographie numérisée - Partie 3: Fonctionnement et interprétation

Zerstörungsfreie Prüfung - Durchstrahlungsverfahren - Computertomographie - Teil 3: Durchführung und Auswertung

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Foreword

This document (EN 16016-3:2011) has been prepared by Technical Committee CEN/TC 138 “Non-destructive testing”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2012, and conflicting national standards shall be withdrawn at the latest by February 2012.

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EN 16016 consists of the following parts:

— *Non destructive testing — Radiation methods — Computed tomography — Part 1: Terminology*;

— *Non destructive testing — Radiation methods — Computed tomography — Part 2: Principle, equipment and samples*;

— *Non destructive testing — Radiation methods — Computed tomography — Part 3: Operation and interpretation*;

— *Non destructive testing — Radiation methods — Computed tomography — Part 4: Qualification*.

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Introduction

This document gives guidelines for the general principles of X-ray computed tomography (CT) applicable to industrial imaging (in the context of this standard, industrial means non-medical applications); it also gives a consistent set of CT performance parameter definitions, including how these 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.

1 Scope

This European Standard specifies an outline of the operation of a CT system, and the interpretation of the results in order to provide the user with technical information to select suitable parameters.

2 Normative references

The following referenced documents are indispensable for the application 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.

EN 16016-1:2011, *Non destructive testing — Radiation method — Computed tomography — Part 1: Terminology*

EN 16016-2:2011, *Non destructive testing — Radiation method — Computed tomography — Part 2: Principle, equipment and samples*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 16016-1:2011 apply.

4 Operational procedure

4.1 General

For target-oriented 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 $\pi/2 \times matrix\,size$ where the matrix size is the number of voxels across the sample diameter or the largest dimension. For more information, refer to 5.5.

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 is determined by the maximum path length, in the material to be X-rayed in accordance with EN 16016-2:2011, 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 prefilters. It should be noted that every prefilter reduces the intensity. Prefilters 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 (post-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 & Z axes.

4.4 Visualisation

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-Iso-surface, 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-Iso-surface. 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 dimension-less). 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.