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Non-destructive testing — Characteristics of focal spots in industrial X-ray systems —

Part 1: Pinhole camera radiographic method

Essais non destructifs — Caractéristiques des foyers émissifs des tubes radiogènes industriels —

Partie 1: Méthode radiographique par sténopé

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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 document should be noted (see www.iso.org/directives).

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This document was prepared by the European Committee for Standardization (CEN) (EN 12543-2:2021) and was adopted (without modification other than those given below) by Technical Committee(s) ISO/TC 135, *Non-destructive testing*, Subcommittee SC 5, *Radiographic testing.*

The main changes are as follows:

— verbal forms in the Scope and 5.1 NOTE have been modified to meet ISO content requirements;

— definitions in Clause 3 have been modified to remove reference to content outside Clause 3;

— Figures 5, 6 and 7 have been updated;

— keys have been added to Figures 1, 2, 3, 4, 5 and 6;

— change "profile integration" to "profile averaging" when referring to the averaging of the profile lines;

— minor editorial corrections.

A list of all parts in the ISO 32543 series can be found on the ISO website.

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

Introduction

In order to cover the large range of effective focal spot sizes, different methods are described in the ISO 32543 series.

The pinhole method of ISO 32543-1 is intended for effective focal spot sizes above 0,1 mm and mainly used for sealed standard and mini focus tubes. ASTM E1165 describes the same pinhole procedure.

The edge method of EN 12543-4 is intended for field applications when the users have to observe the effective focal spot on a regular basis and the pinhole method is non-practical.

The edge measurement method of EN 12543-5 is intended for measurement of effective focal spot sizes between 5 µm and 300 µm and mainly for the use with µ-Focus tubes (up to 100 µm) and mini focus tubes with spot sizes of 100 µm to 300 µm.

In the overlapping ranges, the different parts of the EN 12543 series and ISO 32543 series provide comparable values within ±20 % tolerance.

Non-destructive testing — Characteristics of focal spots in industrial X-ray systems —

Part 1: Pinhole camera radiographic method

1 Scope

This document specifies a method for the measurement of effective focal spot dimensions above 0,1 mm of X-ray systems up to and including 1 000 kV X-ray voltage by means of the pinhole camera method with digital evaluation. The tube voltage applied for this measurement is restricted to 200 kV for visual film evaluation and can be selected higher than 200 kV if digital detectors are used.

The imaging quality and the resolution of X-ray images depend highly on the characteristics of the effective focal spot, in particular the size and the two-dimensional intensity distribution as seen from the detector plane. Compared to the other methods specified in the EN 12543 series and the ISO 32543 series, this method allows to obtain an image of the focal spot and to see the state of it (e.g. cratering of the anode).

This test method provides instructions for determining the effective size (dimensions) of standard (macro focal spots) and mini focal spots of industrial X-ray tubes. This determination is based on the measurement of an image of a focal spot that has been radiographically recorded with a “pinhole” technique and evaluated with a digital method.

For the characterization of commercial X-ray tube types (i.e. for advertising or trade), the specific FS (focal spot) values of Annex A can be used.

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 19232-5, *Non-destructive testing — Image quality of radiographs — Part 5: Determination of the image unsharpness and basic spatial resolution value using duplex wire-type image quality indicators*

3 Terms and definitions

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

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

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

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

3.1
actual focal spot
X-ray emitting area of the anode as viewed from a position perpendicular to the anode surface

Note 1 to entry: The actual focal spot is also called thermal focal spot in other literature.

3.2
effective focal spot
X-rays emitting area of the anode as viewed from the image plane of the detector

Note 1 to entry: The effective focal spot is also called optical focal spot in other literature.

3.3
effective focal spot size
focal spot size measured in accordance with this document

3.4
nominal focal spot size
SS
characteristic value for X-ray tubes having measured spot sizes within a defined range

3.5
focal spot class
FS
number used to classify X-ray tubes based on the nominal focal spot size

3.6
basic spatial resolution of the detector
$SR_b^{detector}$
smallest degree of visible detail within a digital image, determined with the duplex wire image quality indicator (IQI) according to ISO 19232-5 located on the detector (magnification = 1), from the smallest number of the duplex wire pair with less than 20 % modulation depth in a linearized profile and it corresponds to ½ of the detector unsharpness

4 Test equipment

4.1 Essential characteristics of the pinhole

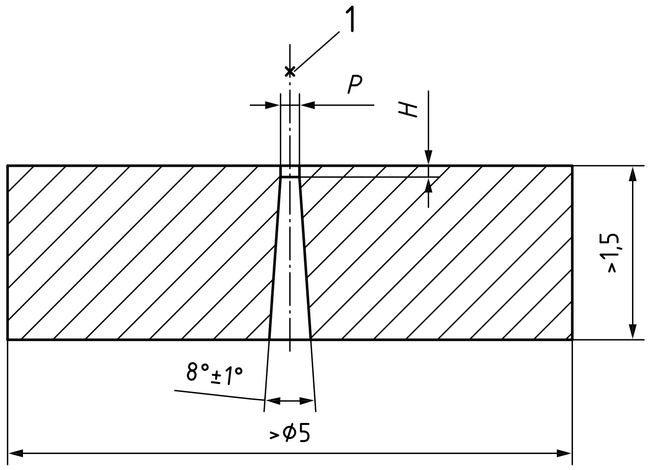
The pinhole camera shall consist of a diaphragm with a pinhole having followed essential dimensions P and H according to Table 1 dependent from the effective focal spot size.

Table 1 — Dimensions of the pinhole

Focal spot size mm	Diameter *P* µm	Height *H* µm
0,1 to 0,3	10 ± 5	20 ± 5
> 0,3 to 1,0	30 ± 5	75 ± 10
> 1,0	100 ± 5	500 ± 10

The essential dimensions *P* and *H* are shown in Figure 1.

Dimensions in millimetres



Key

1 focal spot

P pinhole diameter

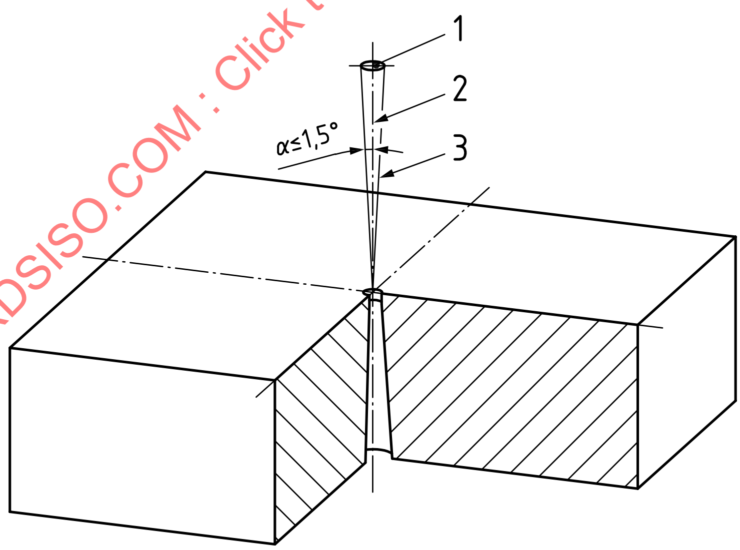
H pinhole height

Figure 1 — Essential dimensions of a pinhole diaphragm

The pinhole diaphragm shall be made of tungsten or of a similar absorbent material (e.g. gold, platinum, tantalum or related alloys).

4.2 Alignment and position of the pinhole camera

The angle between the beam direction and the pinhole axis (see Figure 2) shall be smaller than ±1,5°. When deviating from Figure 2, the direction of the beam shall be indicated.



Key

1 focal spot

2 beam direction

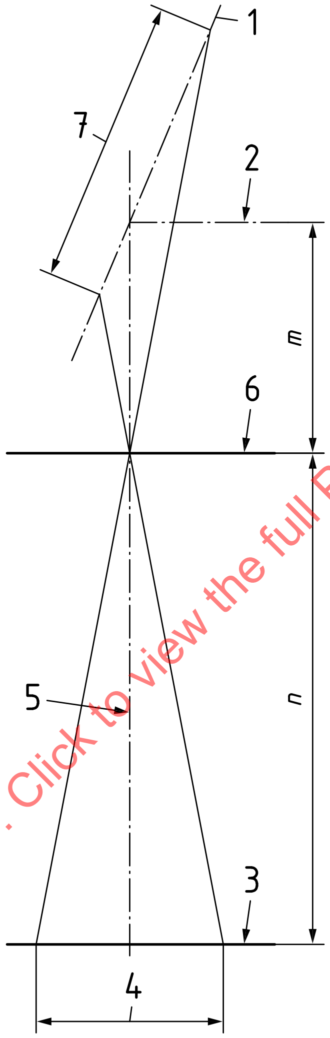
3 maximum deviation of the axis of the pinhole

Figure 2 — Alignment of the pinhole camera

The incident face of the pinhole diaphragm shall be placed at a distance m from the focal spot so that the variation of the magnification over the extension of the actual focal spot does not exceed ±5 % in the beam direction. In no case shall this distance be less than 100 mm.

4.3 Position of the radiographic image detector

The radiographic image detector [film, imaging plate (CR) or digital detector array (DDA)] shall be placed normal to the beam direction at a distance *n* from the incident face of the pinhole diaphragm determined from the applicable magnification according to Figure 3 and Table 2.



Key

1 plane of anode
2 reference plane
3 radiographic image detector
4 magnified length of the effective focal spot
5 beam direction
6 incident face of the diaphragm
7 physical length of the actual focal spot
n distance from pin hole to detector
m distance from focal spot centre to pin hole

Figure 3 — Beam direction dimensions and planes

Table 2 — Magnification for focal spot pinhole images

Anticipated Focal Spot Size *d* mm	Minimum Magnification *n/m*	Distance between Focal Spot and Pinhole *m* m [a]	Distance between Pinhole and Detector *n* m [a]
0,1 to 1,0	5: 1	0,10	0,50
1,0 to 2,0	3: 1	0,25	0,75
> 2,0	1: 1	0,5	0,5

[a] When using a technique that entails the use of enlargement factors and a 1 m focal spot to detector distance (FDD = *m*+*n*) is not possible (see 5.1), the distance between the focal spot and the pinhole (*m*) shall be adjusted to suit the actual focal spot to detector distance (FDD) used (for example, if a 600 mm FDD is used, *m* shall be 100 mm for 5:1 enlargement, 150 mm for 3:1 enlargement, 300 mm for 1:1 enlargement, and the like).

4.4 Requirements on the radiographic image detector

Digital radiographic image detectors can be used instead of film, provided sensitivity, dynamic range and detector unsharpness allow capturing of the full spatial size of the focal spot image without detector saturation. The maximum allowed basic spatial resolution ($SR_b^{detector}$) of the digital detector is determined from the pinhole diameter *P* and magnification *n/m*. It is calculated according to Formula (1).

$$SR_b^{detector} = \frac{P}{2} \cdot \left(1 + \frac{n}{m}\right) \tag{1}$$

The basic spatial resolution of the digital detector ($SR_b^{detector}$) shall be determined with the duplex wire IQI according to ISO 19232-5. For correct quantitative measurements the minimum projected length and width of the focal spot image should be covered always by at least the pixel number which is equivalent to 20 x $SR_b^{detector}$. The signal-to-noise ratio of the focal spot image (ratio of the maximum intensity value inside the focal spot and the standard deviation of the background signal outside) should be at least 70. The maximum intensity inside the focal spot should be above 30 %, but lower than 90 % of the maximum linear detector output value. The grey value resolution of the detector shall be at least 12 bit.

Imaging plate systems (computed radiography, CR) or digital detector arrays (e.g. based on CCD-, amorphous-Si- or CMOS-detectors coupled to an X-ray fluorescence screen, or direct converting detectors) may be used as digital image detectors. The pixel values (grey values) shall be linear to the dose.

If radiographic film is used as image detector, it should meet the requirements of the film system class C 4 or better according to ISO 11699-1 and shall be used without screens. The film shall be exposed to a maximum optical density between 1,5 and 2,5. The film shall be digitized with a maximum pixel size of 50 µm or a smaller size, which shall fulfil the requirements of the above described $SR_b^{detector}$ condition and be evaluated according to 5.3.

If the user has no digital equipment, the film may be evaluated visually; the procedure is described in 5.4. The visual evaluation of film radiographs will be less accurate than the evaluation of digital images with the profile function as described in 5.3.

4.5 Image processing equipment for digital images

This apparatus is used to capture the images and to measure the intensity profile of the focal spot in the projected image. The image shall be a positive image (more X-ray dose shows higher grey values) and linear proportional to the dose.

The equipment shall be able:

— to calibrate the pixel size with a precision of 2 µm or 1 % of the pixel size;

— to draw line profiles and average the line profiles over a pre-set area;

— to integrate line profiles by the length of the line profile;

— to subtract the baseline using a linear interpolation (straight line) of both ends of the line profile using at least the average of 10 % of the line profile as support on both ends; and

— to calculate the width or length of the focal spot in the image with two threshold values of 16 % and 84 % of the averaged line profile and extrapolate to 100 % (see Figure 5 and Figure 6).

When using CR technology or digitized film where outlier pixel may occur a median 3 x 3 filter should be applied.

4.6 Loading factors

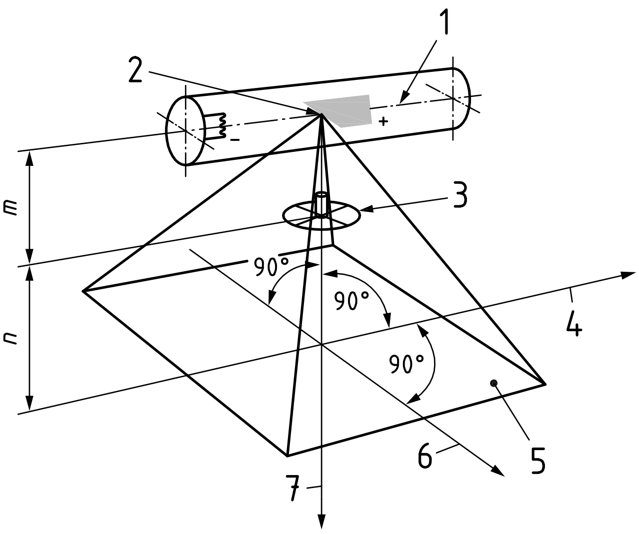
The X-ray tube voltage shall be 75 % of the nominal tube voltage, but not more than 200 kV for evaluation with film. For evaluation with a DDA or CR, the maximum voltage is limited by the condition that the background intensity is lower than the half of the maximum intensity inside the focal spot. The X-ray tube current shall be the maximum applicable tube current at the selected voltage. For measurements with more than 200 kV, an optional copper pre-filter should be used to prevent saturation of the imaging device.

5 Measurement and determination of the focal spot size

5.1 Measurement procedure

If possible, use a standard 1 m focal spot to detector distance (FDD = $m + n$) for all exposures. If the machine geometry or accessibility limitations do not allow the use of an FDD of 1 m, the maximum attainable FDD shall be used. In these cases, the relative distances between focal spot, pinhole, and detector shall be adjusted according to the image enlargement factors specified in Table 2. For small focal spots, FDD should be larger than 1 m to meet the requirements in 4.4 and 5.2. The distance between the focal spot and the pinhole is based on the anticipated size of the focal spot being measured and the desired degree of image enlargement (see Figure 3). The specified focal spot to pinhole distance (m) for the different focal spot size ranges is provided in Table 2. Position the pinhole such that it is within ±1,5° of the central axis of the X-ray beam.

NOTE The accuracy of the pinhole system is especially sensitive to the relative distances between (and alignment of) the focal spot, the pinhole, and the detector. Accordingly, a specially designed apparatus can be used to meet the above requirements. ASTM E1165-20, Figure 6, provides an example of a special collimator that can be used to ensure conformance with ±1° alignment tolerance.



Key

1 longitudinal axis of the X-ray tube assembly
2 focal spot
3 pin hole camera
4 direction of evaluation for the focal spot length
5 image reception plane
6 direction of evaluation for the focal spot width
7 preference axis

Figure 4 — Exposure set-up schematic and specification of focal spot directions

Position the detector as illustrated in Figure 4. When using film as detector, the exposure identification appearing on the film (by radiographic imaging) should be:

— X-ray machine identity (make and serial number);

— organization making the radiograph;

— energy (kV);

— tube current (mA); and

— date of exposure.

If the film is digitized or a digital detector is used, this information shall be stored within the image or file name.

5.2 Measurement with digital technique (preferred method)

The X-ray dose proportional grey scale image of the radiation detector shall be evaluated to measure the dimensions of the focal spot. The detector shall be exposed as given in 4.4. When using CR or film, the maximum pixel value or density shall be controlled by exposure time only. With a DDA the internal detector settings (frame time and/or sensitivity) shall be selected that the conditions of 4.4 are met.

NOTE The required signal-to-noise ratio (SNR) can be achieved with a DDA system by integrating or averaging frames with identical exposures (frame times) in the computer.

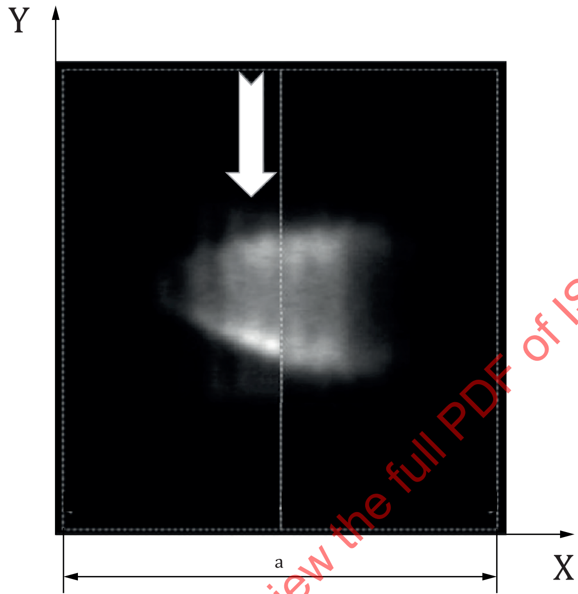
Before evaluation the image shall be inspected for spikes or outliners (CR and digitized film only). These artefacts shall be removed using a median 3 x 3 filter. In this case the size of the focal spot in the image shall be > 40 pixels in both orthogonal directions.

The images shall be stored with the nomenclature of 5.1 in 16-bit lossless image format, e.g. TIFF or DICONDE.

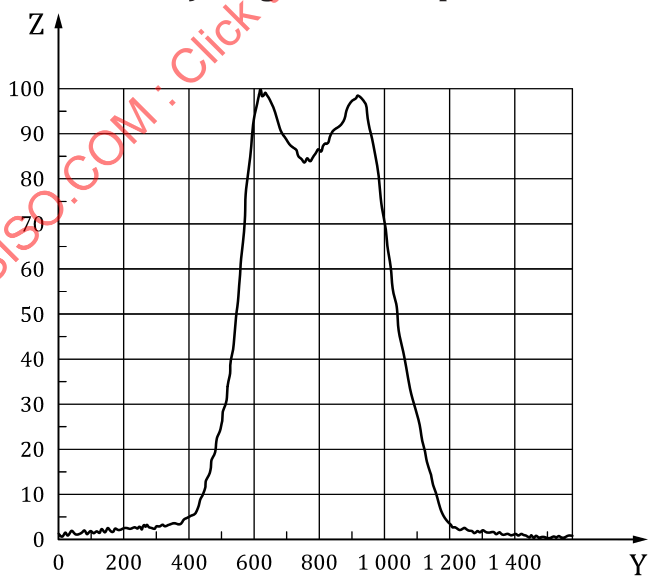
The pixel size in the image shall be calibrated by a known object size in the image like a “ruler” or by measured geometry with the precision of 1 % of the pixel size.

5.3 Evaluation with digital technique using integrated line profiles (ILP)

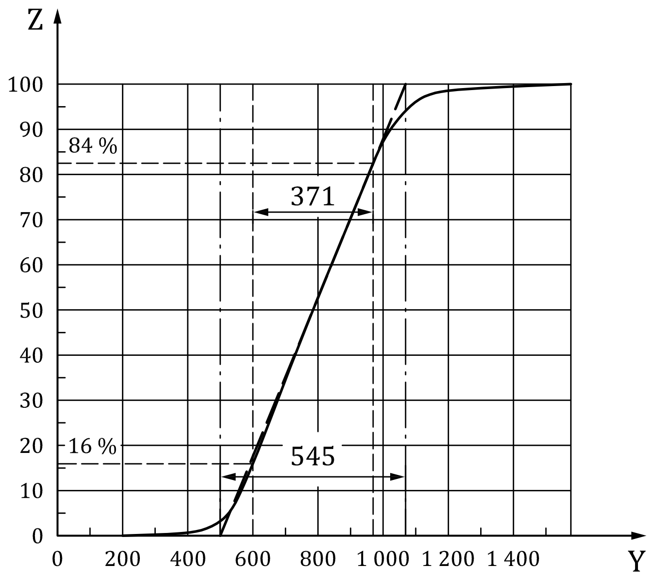
A line profile shall be drawn in length or width direction through the centre of the focal spot. The line profile shall be averaged perpendicular to the profile direction over about 3 times the anticipated focal spot size (see Figure 5 and Figure 6). The line profile should have a length of at least 3 times the anticipated focal spot size. With this procedure an area of nine times the size of the anticipated focal spot size is used for evaluation. The baseline shall be subtracted using a linear interpolation (straight line) of both ends of the line profile, using at least the average of 10 % of the line profile as support on both ends.



a) Image of a focal spot



b) Line profile along the direction of the arrow in Figure 5a



c) Integrated line profile (ILP) of the line profile in Figure 5b

Key

X length axis, in µm

Y width axis, in µm

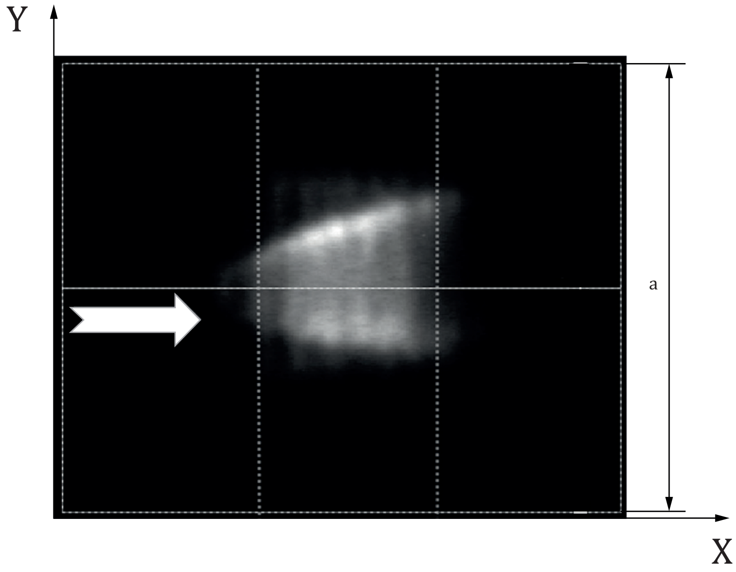
Z radiation intensity, normalized to 100 %

a Average width of the profile.

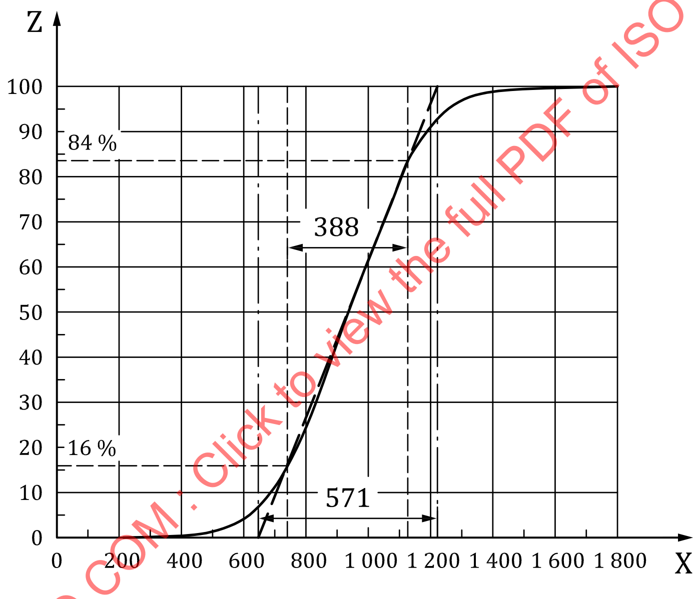
Figure 5 — Example for the Evaluation of effective focal spot width with the integrated line profile (ILP) method

The line profile shall be integrated along the profile by a cumulative integration as shown in Figure 5b and Figure 5c. The points on the resulting curve (see Figure 5c) at which the curve has 16 % and 84 % of its maximum value shall then be determined (method according to Klasens,[5] see Figure 5c). The distance between the 16 % and 84 % points is extrapolated by multiplication with 1,47 to the theoretical values of 0 % and 100 % of the total intensity focal spot, as shown in Figure 5c. The result is the size of the focal spot in the direction of the integrated line profile (ILP).

NOTE By using the values of 16 % and 84 % instead of 0 % and 100 %, the determined size is 32 % too small. The factor 1,47 = 100/(100–32) extrapolates this to 100 %.



a) Pin hole image of the focal spot with ILP integration



b) Evaluation graph with the ILP

Key

X length axis. in µm

Y width axis, in µm

Z radiation intensity, normalized to 100 %

a Average width of the profile.

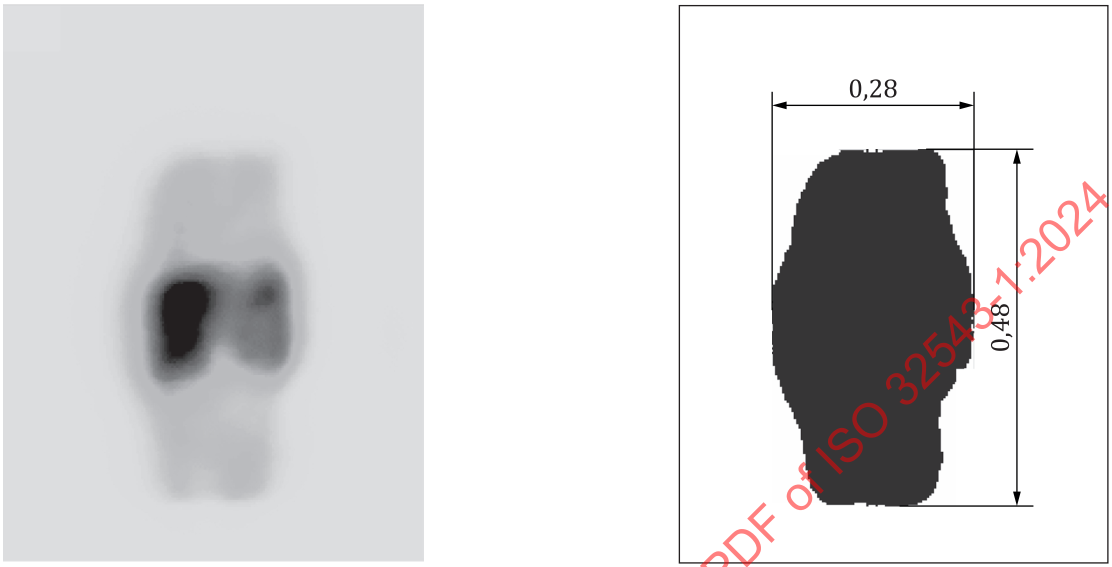
Figure 6 — Example for the evaluation of effective focal spot length with the integrated line profile (ILP) method

This evaluation shall be repeated with the orthogonal direction, see Figure 6a and Figure 6b, where the direction, as shown in Figure 5, is vertical to the electron beam direction (focal spot width) and the direction, as shown in Figure 6, is parallel to the electron beam direction (focal spot length), see Figure 4.

5.4 Measurement of effective focal spot size visually using film radiographs

If radiographic film is used as an image detector and it can't be digitized, it shall be evaluated visually using an illuminator with a uniform luminance of 2 000 cd/m^2 to 3 000 cd/m^2. The visual evaluation shall be carried out using an 5x to 10x magnifying glass, with a built-in reticule, with divisions of 10 % of the magnified spot size but always with divisions ≤ 0,1 mm. The resulting focal spot shall be defined by the visible extent of the blackened area, divided by the selected magnification factor. An example is shown in Figure 7 after digitization. The visual evaluation of films is less accurate than the digital evaluation as described in 5.3 and should be used mainly for monitoring issues.

Dimensions in millimetres



a) X-ray dose proportional grey scale image of a focal spot

b) Evaluation result (binary image) based on a threshold (here 10 %) between background intensity and maximum intensity of the focal spot image

Figure 7 — Example for visual evaluation of focal spot image on radiographic film

6 Classification and result of focal spot size measurement

The focal spot shall be classified according to its measured size. The nominal values of the focal spot sizes and the dedicated classes are consistent with the wire pair stepping as described in ISO 19232-5. The values for width and length shall be measured separately and the larger of both values shall be considered as measured focal spot size d. This focal spot size shall be used to assign the corresponding nominal focal spot size and focal spot class, as shown in Table A.1. An example of a dual focal spot X-ray tube is given in Table A.2.

If measured with film, the report documenting for the focal spot size measurement, determination of the nominal spot size and class shall include the film system class, the X-ray tube name and serial number, the focal spot size(s) that was measured (some X-ray tubes have dual focal spots), the set-up and exposure parameters including kilo voltage, milliamps, magnification (*n*, *m*), pin hole diameter, date, name of operator and organization, and estimated beam time hours (if available). If the digitized film is evaluated, the film scanner type and setting shall be documented.

If measured with a digital detector, the report documenting for the focal spot size measurement, determination of the nominal spot size and class shall include the image name (see 5.1), detector model, used pixel size, measured $SR_b^{detector}$ and serial number, the X-ray tube name and serial number, the focal spot size(s) that was measured (some X-ray tubes have dual focal spots), the set-up and exposure parameters including kilo voltage, milliamps, magnification (*n*, *m*), pin hole diameter, date, name of operator and organization, and estimated beam time hours (if available).

A print of the focal spot image or the digital image file may be added to the report for information purposes.