Standard Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging[1]

1. Scope

1.1 The image quality and the resolution of X-ray images highly depend on the characteristics of the focal spot. The imaging qualities of the focal spot are based on its two dimensional intensity distribution as seen from the detector plane.

1.2 This test method provides instructions for determining the effective size (dimensions) of standard 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.

1.3 This standard specifies a method for the measurement of focal spot dimensions from 50 µm up to several mm of X-ray sources up to 1000 kV tube voltage. Smaller focal spots should be measured using EN 12543-5 using the projection of an edge.

1.4 This test method may also be used to determine the presence or extent of focal spot damage or deterioration that may have occurred due to tube age, tube overloading, and the like. This would entail the production of a focal spot radiograph (with the pinhole method) and an evaluation of the resultant image for pitting, cracking, and the like.

1.5 Values stated in SI units are to be regarded as the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1000 Guide for Radioscopy

E1255 Practice for Radioscopy

E2002 Practice for Determining Total Image Unsharpness in Radiology

E2033 Practice for Computed Radiology (Photostimulable Luminescence Method)

E2698 Practice for Radiological Examination Using Digital Detector Arrays

2.2 *European Standards:*[3]

EN 12543-2 Non-destructive testing—Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing—Part 2: Pinhole camera radiographic method

EN 12543-5 Non-destructive testing—Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing—Part 5: Measurement of the effective focal spot size of mini and micro focus X-ray tubes

2.3 *Papers:*

Klaus Bavendiek, Uwe Heike, Uwe Zscherpel, Uwe Ewert And Adrian Riedo, "New measurement methods of focal spot size and shape of X-ray tubes in digital radiological applications in comparison to current standards," WC-NDT 2012, Durban, South Africa

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *actual focal spot*—the X-ray producing area of the target as viewed from a position perpendicular to the target surface (see Fig. 1).

3.1.2 *effective focal spot*—the X-ray producing area of the target as viewed from a position perpendicular to the tube axis in the center of the X-ray beam (see Fig. 1).

3.1.3 *effective size of focal spot*—focal spot size measured in accordance with this standard.

4. Summary of Test Method

4.1 This method is based on a projection image of the focal spot using a pinhole camera. This image shows the intensity distribution of the focal spot. From this image the effective size of the focal spot is computed. A double integration of a profile

[1] This test method is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.01 on Radiology (X and Gamma) Method.

Current edition approved June 15, 2012. Published September 2012. Originally approved in 1987. Last previous edition approved in 2010 as E1165 – 04 (2010). DOI: 10.1520/E1165-04R12.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from European Committee for Standardization (CEN), Avenue Marnix 17, B-1000, Brussels, Belgium, http://www.cen.eu.

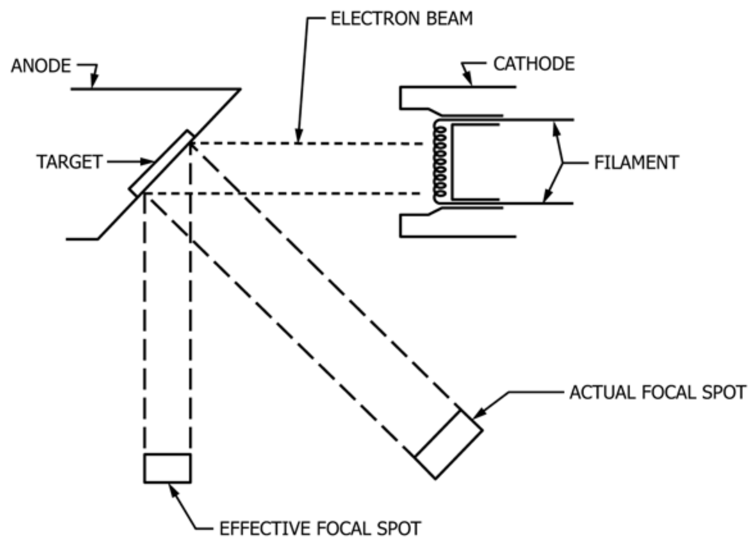


FIG. 1 Actual/Effective Focal Spot

across the pinhole image transforms the pinhole image into an edge profile. The X- and Y-dimension of the edge unsharpness is used for calculation of the size of the focal spot. This method provides similar results as the method described in EN 12543-5 using an edge target instead of a pinhole camera. The measured effective spot sizes correspond to the geometrical image unsharpness values at given magnifications as measured with the ASTM E2002 duplex wire gauge in practical images using equation:

$$u_G = \Phi(v - 1) \quad (1)$$

with geometrical unsharpness u_G, focal spot size Φ and magnification v (see ASTM E1000 for details of this equation). For a full description see Reference 2.3.

4.2 Additionally, a simplified test method is described in the annex A for users of X-ray tubes who may not intend to use a pinhole camera. This alternative method is based on the edge method in accordance with EN 12543-5 using a plate hole IQI as described in ASTM E1025 or E1742 instead of a pinhole camera.

5. Significance and Use

5.1 One of the factors affecting the quality of radiologic images is the geometric unsharpness. The degree of geometric unsharpness is dependent on the focal spot size of the radiation source, the distance between the source and the object to be radiographed, and the distance between the object to be radiographed and the detector (imaging plate, Digital Detector Array (DDA) or film). This test method allows the user to determine the effective focal size of the X-ray source. This result may then be used to establish source to object and object to detector distances appropriate for maintaining the desired degree of geometric unsharpness and/or maximum magnification for a given radiographic imaging application. Some ASTM standards require this value for calculation of a required magnification, for example, E1255, E2033, and E2698.

6. Apparatus

6.1 *Pinhole Diaphragm*—The pinhole diaphragm shall conform to the design and material requirements of Table 1 and Fig. 3.

6.2 *Camera*—The pinhole camera assembly consists of the pinhole diaphragm, the shielding material to which it is affixed, and any mechanism that is used to hold the shield/diaphragm in position (jigs, fixtures, brackets, and the like).

6.3 *Alignment and Position of the Pinhole Camera*—The angle between the beam direction and the pinhole axis (see Fig. 4) shall be smaller than ±1.5°. When deviating from Fig. 4, the direction of the beam shall be indicated. 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.

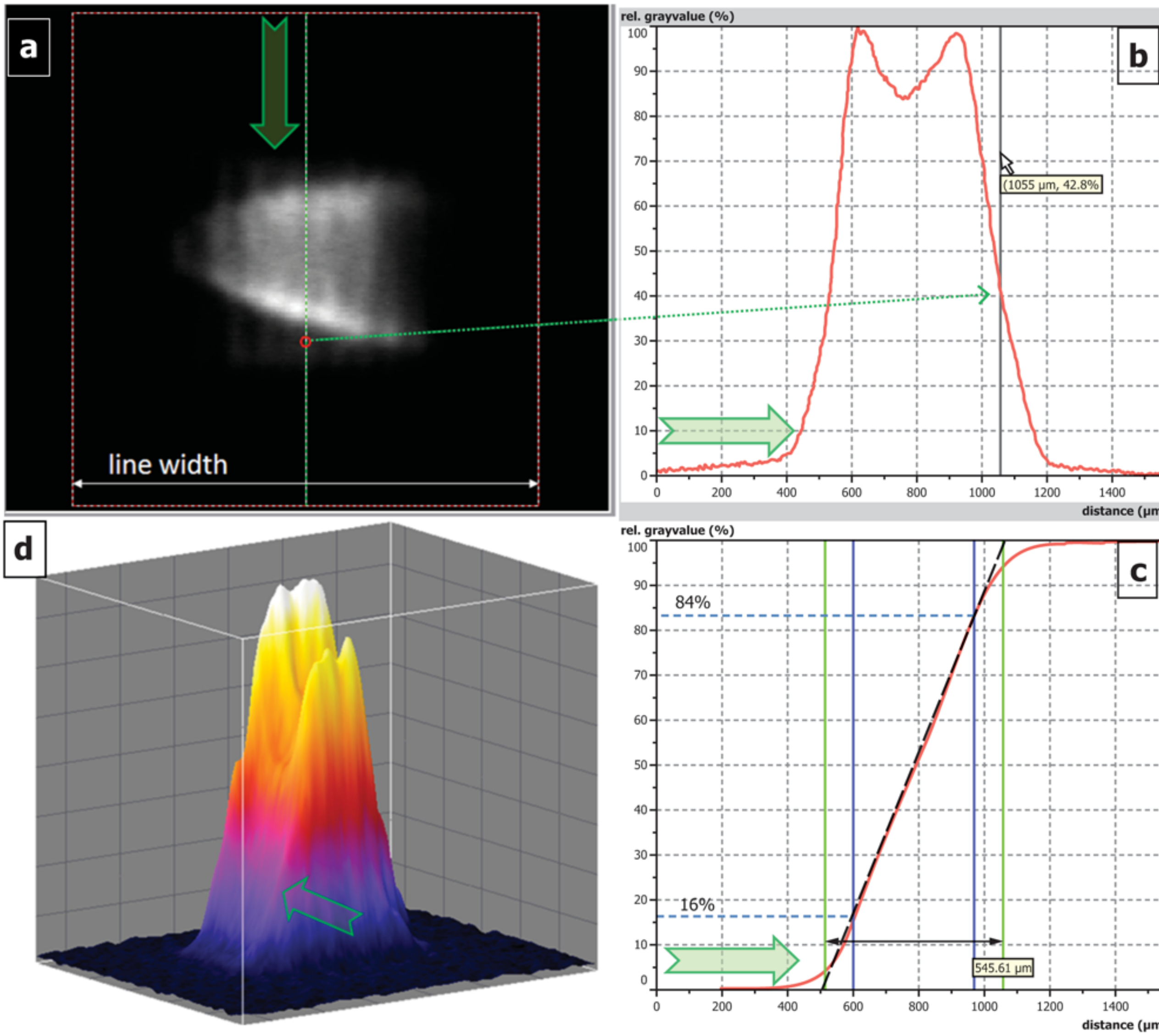
6.4 *Position of the Radiographic Image Detector*—The radiographic image detector (film, imaging plate or DDA) shall be placed normal to the beam direction at a distance *n* from the incident face of the pinhole diaphragm determined from the applicable magnification according to Fig. 5 and Table 2.

TABLE 1 Pinhole Diaphragm Design Requirements (Dimension)[A]

NOTE 1—The pinhole diaphragm shall be made from one of the following materials: *(1)* An alloy of 90 % gold and 10 % platinum, *(2)* Tungsten, *(3)* Tungsten carbide, *(4)* Tungsten alloy, *(5)* Platinum and 10 % Iridium Alloy, or *(6)* Tantalum.

Focal Spot Size mm	Diameter P µm	Height H µm
0.05 to 0.3	10 ± 5	50 ± 5
0.3 to 0.8	30 ± 5	75 ± 10
>0.8	100 ± 5	500 ± 10

[A] See Fig. 3.



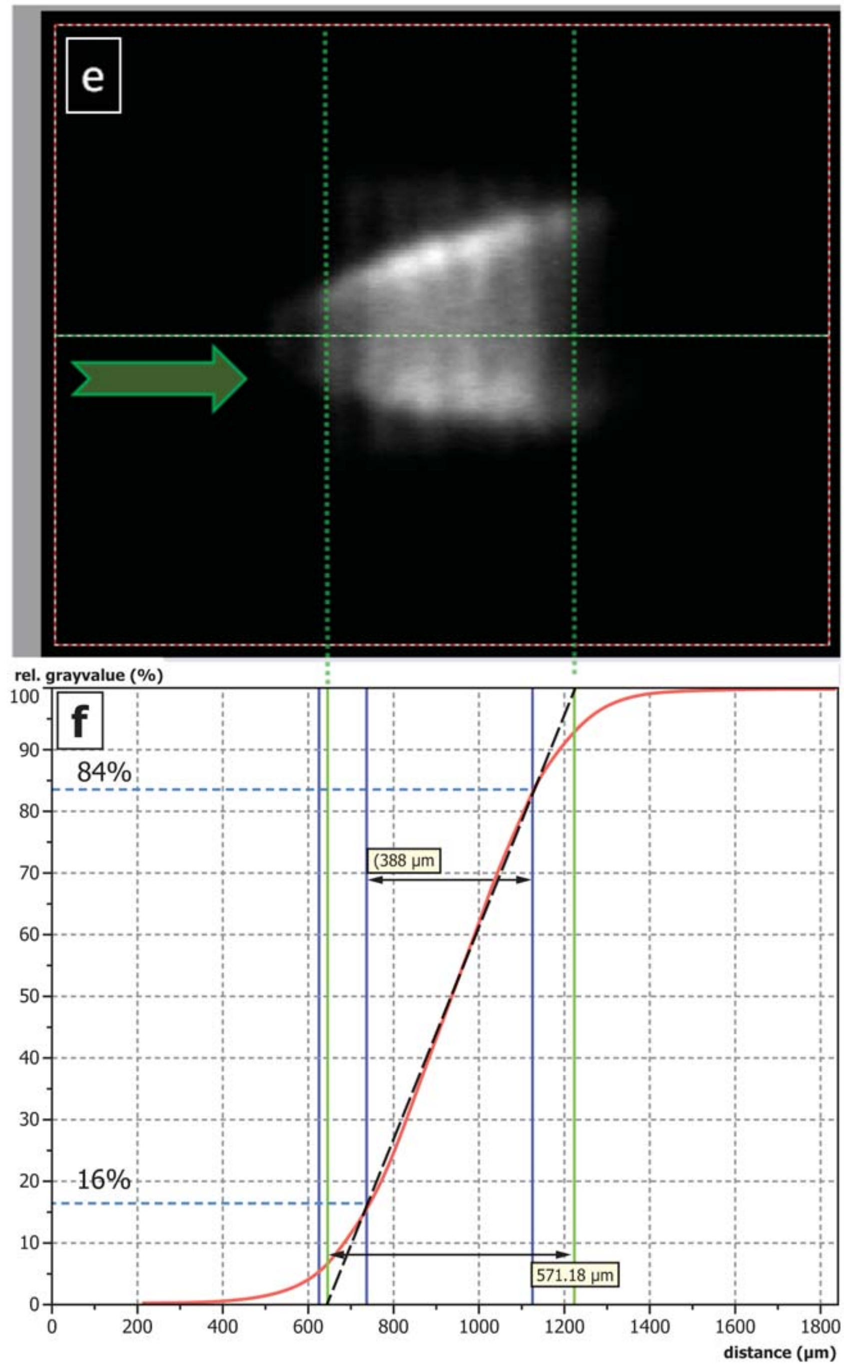
(a) Image of a double line Focal Spot with the Location and Size of the Line Profile in Length Direction.
(b) Line Profile in the direction of the large arrow averaged over the dotted rectangle of Fig. 2a.
(c) Integrated Line Profile with Markers (blue) for 16 % and 84 % of the Profile Intensity, Markers (green) for 0 % and 100 % Extrapolation and the Extrapolation Line (dotted black), corresponding to the Klasens method of E1000.
(d) Pseudo 3D Image of the Focal Spot; the large arrow points in the direction of the Line Profile.
(e) Image of a double line Focal Spot with the Location and Size of the Line Profile in Width Direction.
(f) Integrated Line Profile with Markers (blue) for 16 % and 84 % of the Profile Intensity, Markers (green) for 0 % and 100 % Extrapolation and the Extrapolation Line (dotted black) for the Width Direction.

FIG. 2 Example for the Measurement of Effective Focal Spot Length and Width with the Integrated Line Profile (ILP) Method

6.5 *Radiographic Image Detector*—Analogue or digital radiographic image detectors may be used, 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 detector unsharpness is given by the geometrical unsharpness u_G of the pinhole and the pinhole diameter P. It is calculated according to (see Fig. 5).

$$u_G = P(1+n/m) \tag{2}$$

6.5.1 The detector unsharpness shall be determined with the duplex wire IQI in accordance with ASTM E2002. The minimum projected length and width of the focal spot image should be covered always by at least 20 detector pixels in digital images. 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 50. The maximum intensity inside the focal spot



(e) Image of a double line Focal Spot with the Location and Size of the Line Profile in Width Direction.
(f) Integrated Line Profile with Markers (blue) for 16 % and 84 % of the Profile Intensity, Markers (green) for 0 % and 100 % Extrapolation and the Extrapolation Line (dotted black) for the Width Direction.

FIG. 2 Example for the Measurement of Effective Focal Spot Length and Width with the Integrated Line Profile (ILP) Method *(continued)*

should be above 30 %, but lower than 90 % of the maximum linear detector output value. The grey value resolution of the detector shall be in minimum 12 Bit.

6.5.2 Imaging plate systems (Computed Radiography, CR) or digital detector arrays (DDA) may be used as digital image detectors following practices E2033 or E2698. The pixel values shall be linear to the dose.

6.5.3 If radiographic film is used as image detector, it shall meet the requirements of E1815 film system class I or Special and shall be packed in low absorption cassettes using no 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 of 50 µm or a smaller size, which fulfills the requirements of the above unsharpness conditions and be

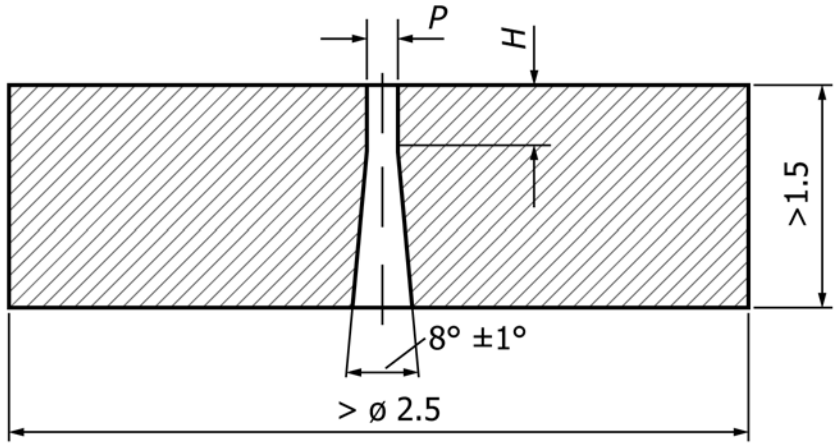


FIG. 3 Essential Dimensions of the Pinhole Diaphragm

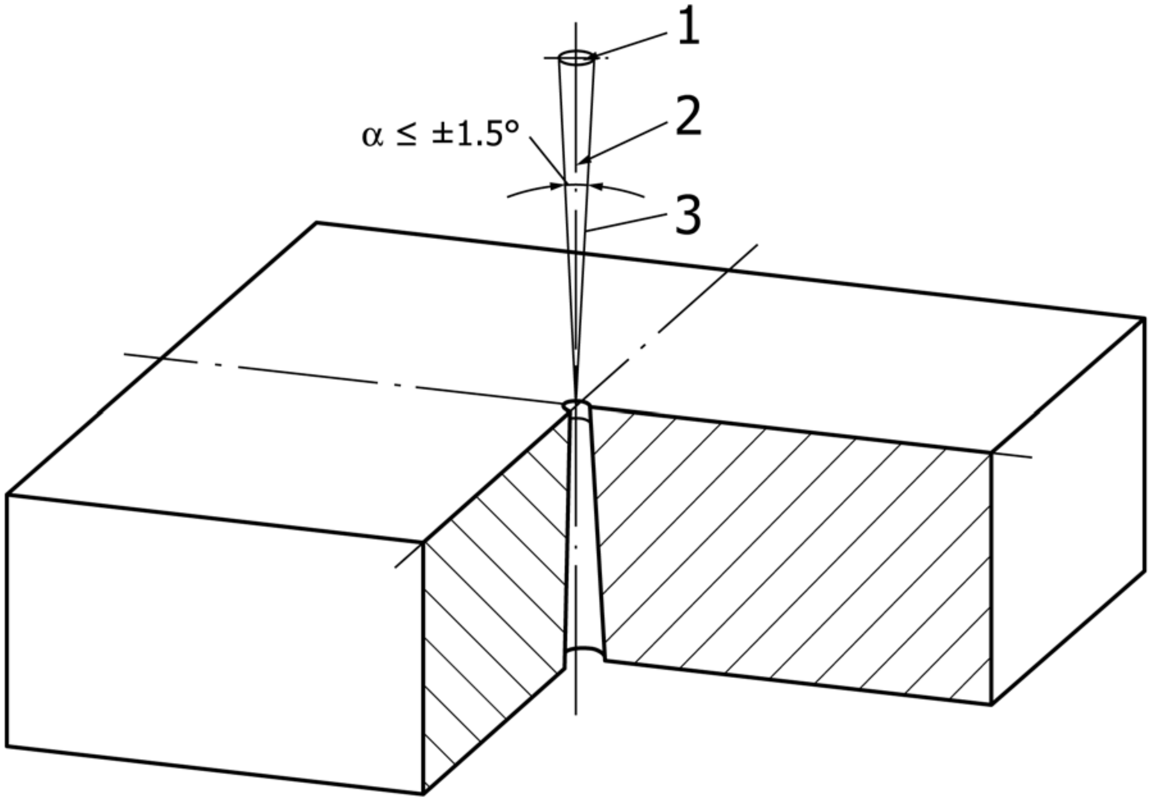


FIG. 4 Alignment of the Pinhole Diaphragm

evaluated according to Eq 2. If the user has no digital equipment the film may be evaluated visually; the procedure is shown in 7.9. The film shall be processed in accordance with Guide E999.

6.6 *Image Processing Equipment*—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 dose shows higher grey values) and linear proportional to the dose. The equipment shall be able:

(1) to calibrate the pixel size with a precision of 2 µm or 1 % of the pixel size,

(2) to draw line profiles and average the line profiles over a preset area,

(3) to integrate line profiles by the length of the line profile,

(4) to subtract the background 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

(5) to calculate the X- and Y-dimension of the focal spot in the image with two threshold values of 16 % and 84 % of the integrated line profile and extrapolate the width to 100 % (see Fig. 2).

NOTE 1—The software for this calculation can be downloaded from

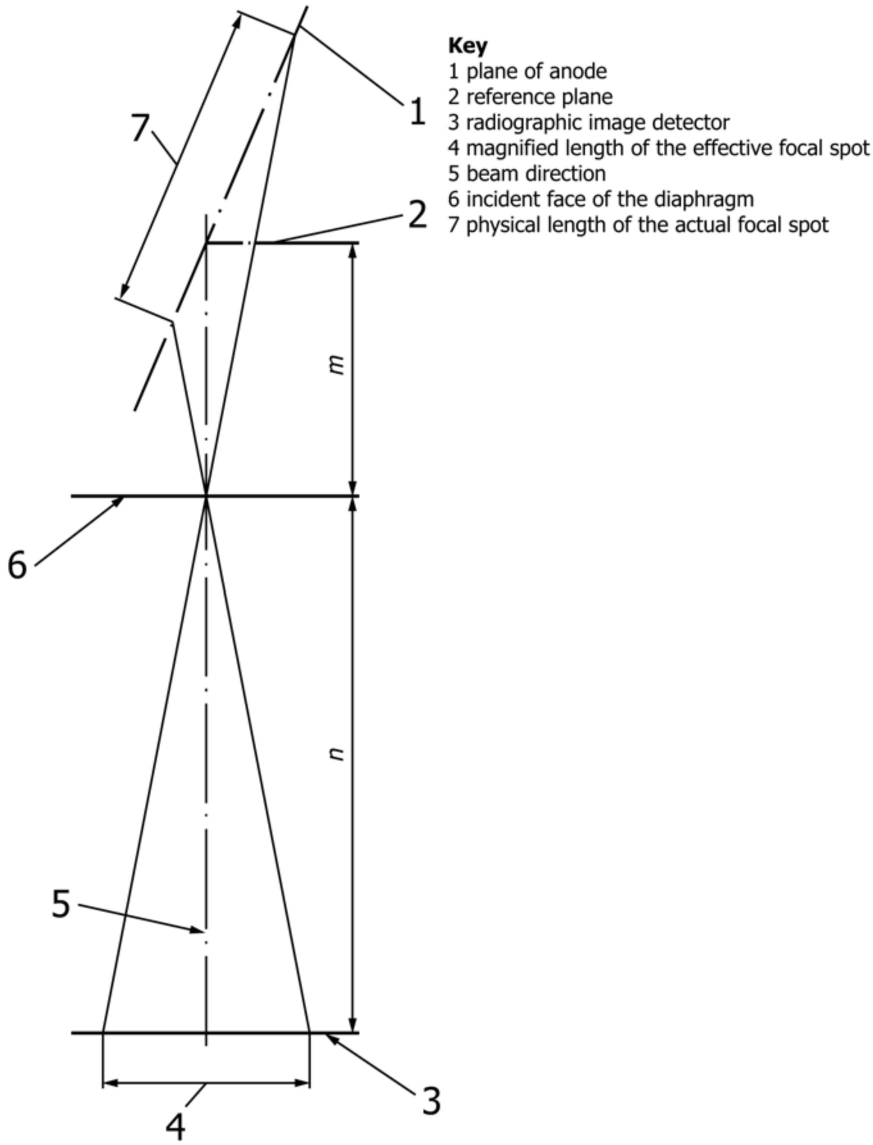


FIG. 5 Beam Direction Dimensions and Planes

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][A]	Distance between Pinhole and Detector [n][A]
0.05 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 7.1), 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 150 mm for 3:1 enlargement, 300 mm for 1:1 enlargement, and the like).

http://dir.bam.de/ic (or http://www.kb.bam.de/~alex/ic/index.html).

6.6.1 When using CR technology or digitized film where outliner pixel may occur, a median 3×3 filter shall be available.

7. Procedure

7.1 If possible, use a standard 1 m (40 in.) focal spot to detector distance (FDD = *m*+*n*) for all exposures. If the machine geometry or accessibility limitations will not permit the use of a 1 m FDD, use the maximum attainable FDD (in these instances adjust the relative distances between focal spot, pinhole, and detector accordingly to suit the image enlargement factors specified in Table 2). For small focal spots FDD may be larger than 1 m (40 in.) to meet the requirements in 6.5 and 7.5. 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 Fig. 5). 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 2—The accuracy of the pinhole system is highly dependent upon the relative distances between (and alignment of) the focal spot, the pinhole, and the detector. Accordingly, a specially designed apparatus may be necessary in order to assure compliance with the above requirements. Fig. 6 provides an example of a special collimator that can be used to ensure conformance even with ±1° alignment tolerance.

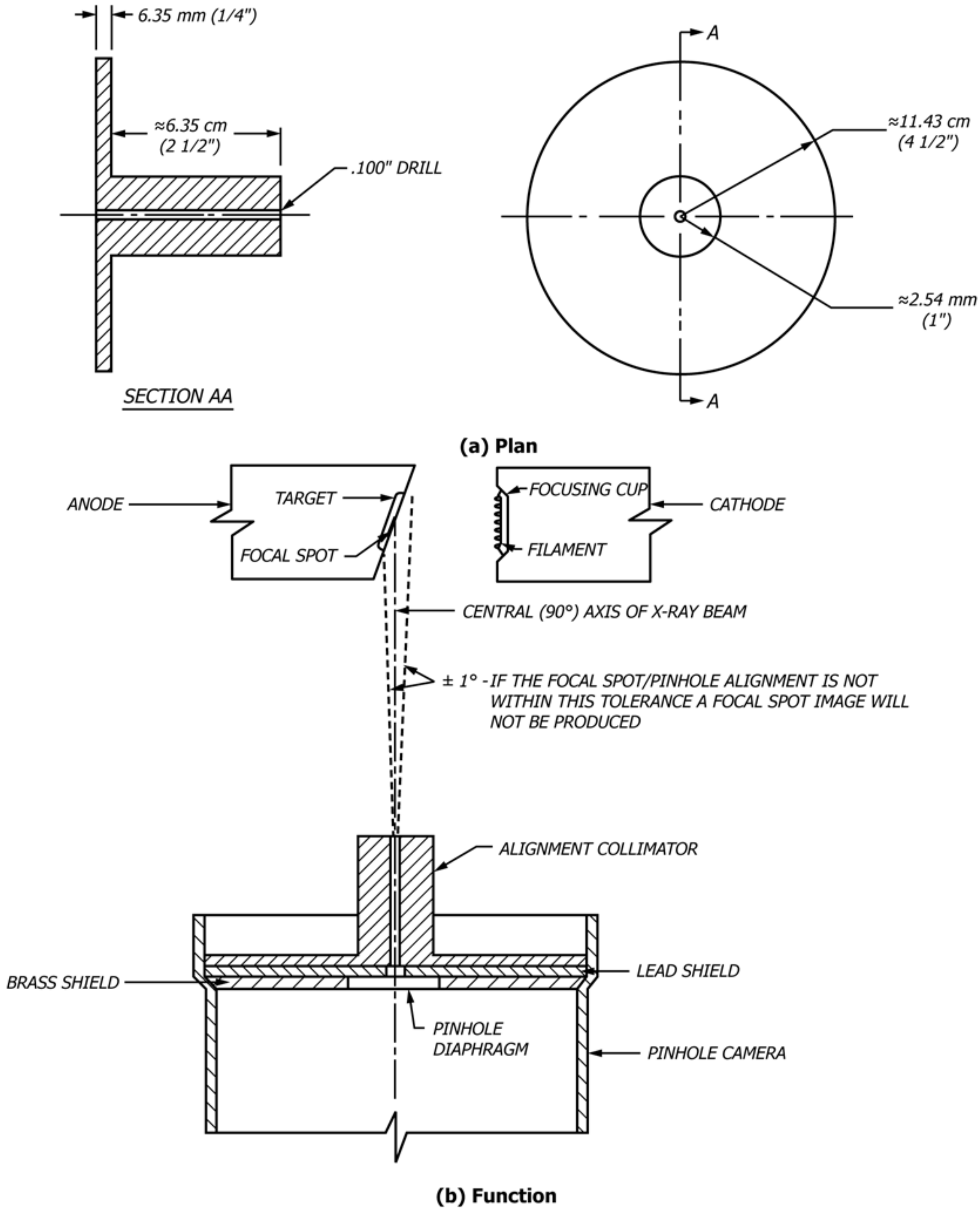


FIG. 6 Exposure Set-Up Schematic

7.2 Position the detector as illustrated in Fig. 7. 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. When the film is digitized or a digital detector is used, this information shall be stored within the image or file name.

7.3 Adjust the kilovoltage settings on the X-ray machine to 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 prefilter may be used to prevent saturation of the imaging device.

7.4 Expose the detector as given in 6.5. 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 6.5 are met.

NOTE 3—The required SNR can be achieved with a DDA system by

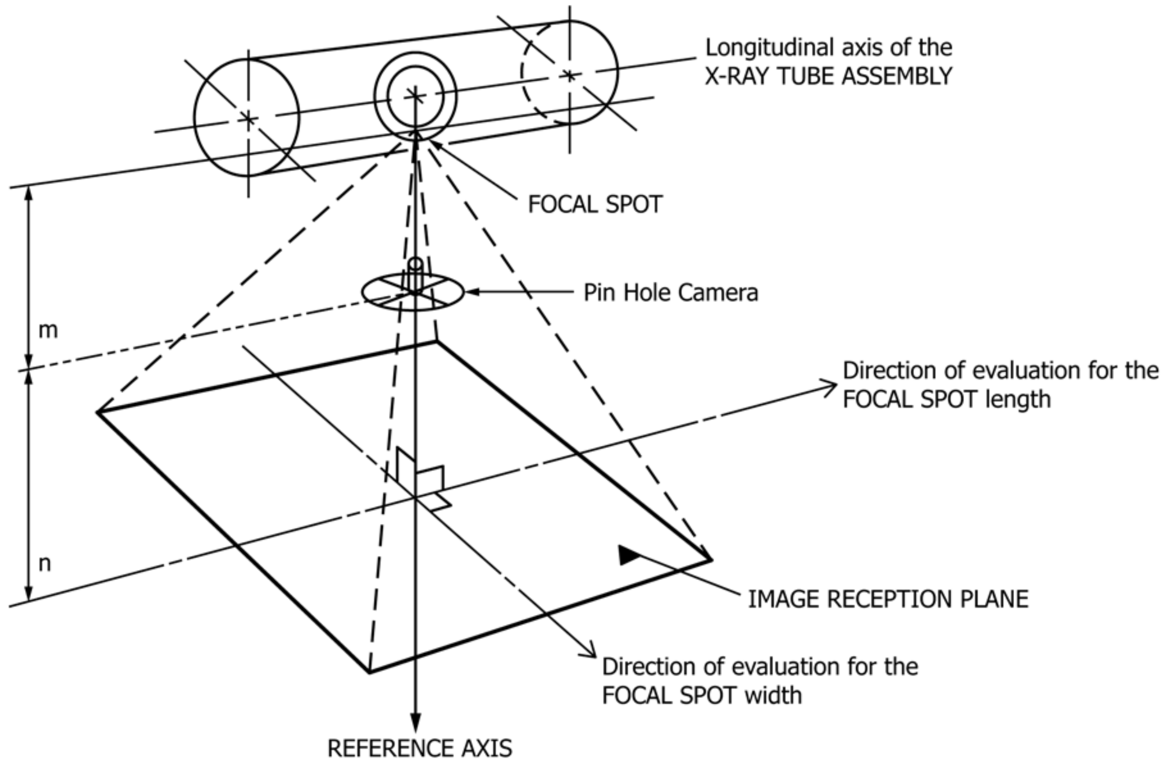


FIG. 7 Exposure Set-Up Schematic and Focal Spot WIDTH (X) and LENGTH (Y) Specification

integration of frames with identical exposures in the computer. For detail refer to ASTM E2736.

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

7.6 The images shall be stored with the nomenclature of 7.2 in 16 Bit lossless Image Format, for example, TIFF or DICONDE.

7.7 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.

7.8 *Focal Spot Measurement using Integrated Line Profiles (ILP):*

7.8.1 A line profile shall be drawn in length or width direction through the maximum intensity of the focal spot. The line profile shall be accumulated perpendicular to the profile direction over about 3 times the anticipated focal spot size (see Fig. 2). The line profile should have a length of at least 3 times the anticipated focal spot size. The background 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. Now the line profile shall be integrated (accumulated). Then the points on the resulting curve at which the curve has 16 % and 84 % of its max value shall be determined (see Klasens method of E1000, and Fig. 16 in E1000). The distance between these points is extrapolated to the theoretical 0 % and 100 % values of the total focal spot intensity by a multiplication with 1.47. The result is the size of the focal spot in the direction of the integrated line profile.

NOTE 4—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 %.

7.8.2 This measurement shall be done in two directions (see Fig. 2 and Fig. 7):

7.8.2.1 *Direction X*—Vertical to the electron beam direction (width).

7.8.2.2 *Direction Y*—Parallel to the electron beam direction (length).

7.9 *Focal Spot Evaluation for Users Without Digital Equipment:*

7.9.1 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 2000 to 3000 cd/m^2. The visual evaluation shall be carried out using an ×5 or ×10 magnifying glass, with a built-in reticle, with divisions of 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 Fig. 8.

8. Classification and Report

8.1 The focal spot shall be classified according to its measured size. The preferred values of focal spot sizes and dedicated classes are consistent with ASTM E2002. The values for width and length shall be taken separately and the maximum determines the focal spot class as shown in Table 3. An example of a dual focal spot X-ray tube is given in Table 4.

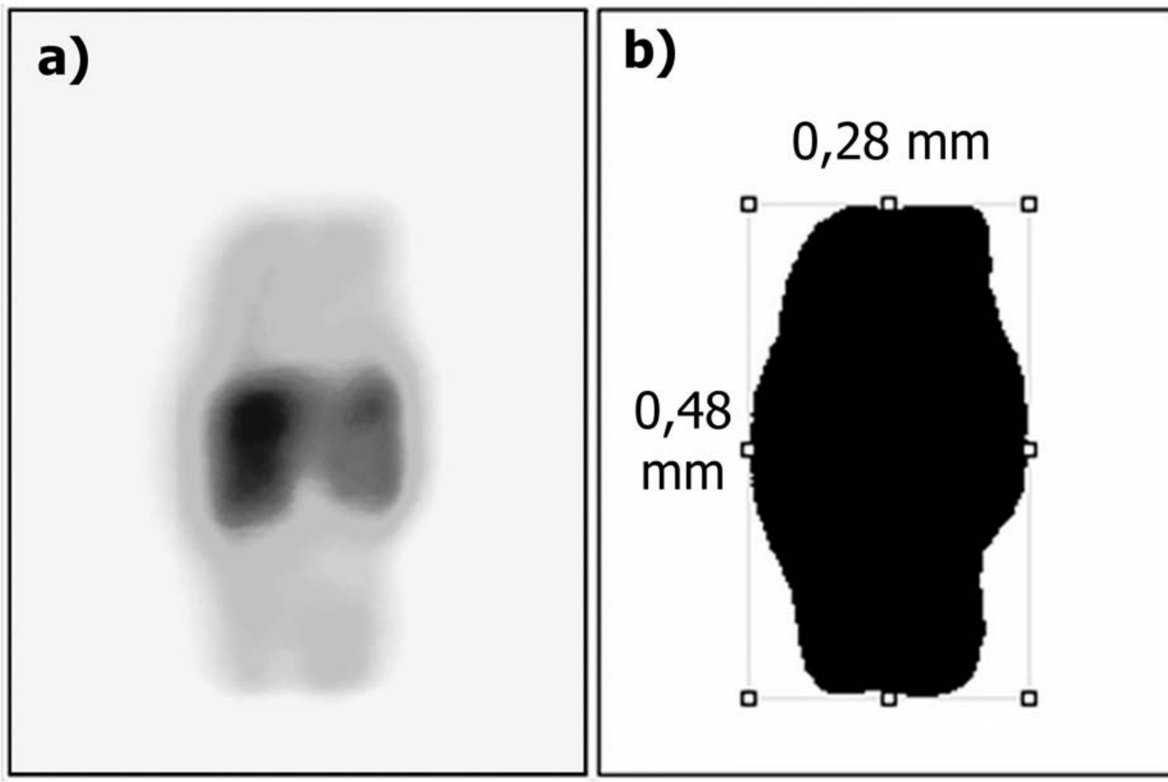


FIG. 8 Example of Visual Film Evaluation with Magnifying Glass

TABLE 3 Preferred Values of Focal Spot Sizes and Dedicated Classes

FS 0				FS	>	4	mm
FS 1	4	mm	≥	FS	>	3.2	mm
FS 2	3.2	mm	≥	FS	>	2.5	mm
FS 3	2.5	mm	≥	FS	>	2	mm
FS 4	2	mm	≥	FS	>	1.6	mm
FS 5	1.6	mm	≥	FS	>	1.27	mm
FS 6	1.27	mm	≥	FS	>	1	mm
FS 7	1	mm	≥	FS	>	0.8	mm
FS 8	0.8	mm	≥	FS	>	0.63	mm
FS 9	0.63	mm	≥	FS	>	0.5	mm
FS 10	0.5	mm	≥	FS	>	0.4	mm
FS 11	0.4	mm	≥	FS	>	0.32	mm
FS 12	0.32	mm	≥	FS	>	0.25	mm
FS 13	0.25	mm	≥	FS	>	0.2	mm
FS 14	0.2	mm	≥	FS	>	0.16	mm
FS 15	0.16	mm	≥	FS	>	0.127	mm
FS 16	0.127	mm	≥	FS	>	0.1	mm
FS 17	0.1	mm	≥	FS	>	0.08	mm
FS 18	0.08	mm	≥	FS	>	0.063	mm
FS 19	0.063	mm	≥	FS	>	0.05	mm
FS 20	0.05	mm	≥	FS	>	0.04	mm

TABLE 4 Example of Classification Result

Company XXR 225-22							
	Measured Width (X)		Measured Length (Y)	Reported Width (X)		Reported Length (Y)	Focal Spot Class
Large Focus (3000W)	2.32 mm	×	1.63 mm	2.5 mm	×	2.0 mm	FS3
Small Focus (640W)	0.461 mm	×	0.452 mm	0.5 mm	×	0.5 mm	FS10

8.2 A report documenting the focal spot size determination should include the image name (see 7.6), machine model number and serial number, the X-ray tube serial number, the focal spot(s) that was measured (some X-ray tubes have dual focal spots), the set-up and exposure parameters (for example, kilovoltage, milliamps, enlargement factor, and the like), date, name of organization, and estimated beam time hours (if available).

8.3 A print of the focal spot image may be added to the report for information purposes only.

9. Precision and Bias

9.1 *Statement of Precision:*

9.1.1 There is no standard x-ray tube focal spot that can be measured and compared to the measurement results; therefore, repeatability precision is defined as the comparison of repeated measurements of a given focal spot with different hardware and within three different laborites. A round robin test report in accordance with ASTM E691 was done with a 160 kV /HP11 tube, using CR technology with 5 different CR plates. The parameter were: 120 kV, 5.3 mA, 20 s exposure time, magnification 4.25, pinhole diameter 30 µm, scanner pixel size 25 µm (5.9 µm effective pixel size), SNR = 78.

9.1.2 The mean value of the length of the focal spot is 0.5553 mm and the width 0.5510 mm. The standard deviation is 0.004937 mm for the length and 0.00446 mm for the width (0.89 % and 0.81 %). In the ASTM E691 evaluation the external and internal consistency values are within the critical interval of 0.5 % significance level for focal spot length and width.

9.2 *Statement on Bias:*

9.2.1 There is no standard x-ray tube focal spot size that can be measured and compared to the measurement results; therefore, a bias can not be measured. Due to the measurement procedure there is no identified cause for a bias.

10. Keywords

10.1 focal spot; pinhole camera; pinhole imaging; X-ray; X-ray tube

ANNEX

(Mandatory Information)

A1. ALTERNATE FOCAL SPOT MEASUREMENT METHOD FOR END USERS

A1.1 Scope

A1.1.1 User of X-Ray tubes may use alternatively an ASTM plate hole IQI for measurement of the focal spot size. This method should provide equivalent values as the method described above but with less accuracy.

A1.2 Background Information for Calculation of Unsharpness Due to Focal Spot Size

A1.2.1 ASTM E2698 uses a formula to calculate the total unsharpness in the image. As shown in ASTM E1000 two reasons can be separated: Unsharpness from the detector and unsharpness from the focal spot size and geometrical magnification.

$$U_{Im} = \frac{1}{v} \cdot \sqrt[3]{U_g^3 + (1.6 \cdot SR_b)^3} \quad \text{(A1.1)}$$

$$U_g = (v - 1) \cdot \Phi \quad \text{(A1.2)}$$

A1.2.1.1 The part from the focal spot is given in ASTM E1000 as shown in Eq A1.2 and can be extracted from Eq A1.1:

$$U_g = v \cdot \sqrt[3]{U_{Im}^3 - \left(\frac{1.6}{v} \cdot SR_b\right)^3} \quad \text{(A1.3)}$$

A1.2.1.2 Bringing Eq A1.2 into Eq A1.3 the focal spot size can be written as:

$$\Phi = FS = \frac{v}{v - 1} \sqrt[3]{U_{Im}^3 - \left(\frac{1.6}{v} \cdot SR_b\right)^3} \quad \text{(A1.4)}$$

A1.2.1.3 Practical tests have shown and in Wagner[4] is calculated that the square root fits better for this measurement procedure. With that the unsharpness from focal spot size in the image shall be calculated by:

$$\Phi = FS = \frac{v}{v - 1} \sqrt[2]{U_{Im}^2 - \left(\frac{2.0}{v} \cdot SR_b\right)^2} \quad \text{(A1.5)}$$

A1.2.1.4 This method uses the edges of a large hole in a thin plate for measurement of the focal spot size. The method is similar to the EN 12543-5. Here, instead of wires or spheres of high absorbing material, hole type IQIs are used.

A1.3 Apparatus

A1.3.1 *ASTM E1025 or E1742 IQI*—The type of IQI should fit to the focal spot size (see Table A1 and Fig. A1.1). The material should be stainless steel or copper. The IQI shall be placed on a shim block of stainless steel, brass or copper and the material thickness of the shim block shall be two time the thickness of the IQI in use.

A1.3.2 *Radiographic Image Detector*—A radiographic image detector which is used in the x-ray system shall also be used for image capture.

[4] Robert F. Wagner et al, Toward a unified view of radiological imaging systems; Part I (1974) and Part II (1977).

FIG. A1.1 ASTM IQIs for Measurement of Spot Size by Edge Evaluation

A1.3.3 *Image Processing Equipment*—This apparatus is used to capture the images. The image shall be linear proportional to the dose. The equipment shall be able:

(1) to calibrate the pixel size with a precision of 1 µm or 1/100 of the anticipated focal spot size—whatever is larger,

(2) to draw averaged line profiles with a width which is adjustable, and

(3) to measure distances in the line profile with the precision of 1/50 of the anticipated focal spot size (see Fig. A1.2).

(4) (optional) a software routine shall be available which is doing the calibration of measurement of the edge unsharpness automatically using the hole size, the pixel size and SR_b as reference for the calibration (see Fig. A1.3).

A1.4 Procedure

A1.4.1 The evaluation shall be done in the X-ray system where the X-ray tube is integrated.

A1.4.2 The IQI should be placed on a Brass, Copper or Inconel shim block with two times the thickness (*t*) of the thickness of the IQI (*T*):

$$t\ 2 \cdot T \tag{A1.6}$$

A1.4.2.1 The IQI hole diameter shall fit to the anticipated focal spot size (afs). The diameter of the hole shall be smaller than fifteen times the anticipated focal spot size and larger than two times the focal spot size.

A1.4.2.2 The energy shall be 75 % (±5 %) of maximum energy of the tube but not more than the maximum voltage used in all applications. The tube current shall be the maximum which is possible at that voltage. The exposure time (CR) or the internal integration time and sensitivity (DDA and Radioscopy) shall be adjusted that the signal in the hole of the IQI is in the range of 30 % to 90 % of the maximum signal possible. The area of the IQI beside the hole shall have a signal of in minimum 10 % of the maximum signal possible. If these conditions cannot be achieved with the setup, a thinner or thicker IQI shall be used together with an adapted shim block. The 2T hole or the 4T hole should be used. A minimum magnification of 2 shall be used.

A1.4.2.3 Furthermore, the minimum magnification v_{min} shall be selected in relation to the effective pixel size SR_b determined with the duplex wire IQI in accordance with ASTM E2002 and afs:

$$v_{min} = 5 \cdot SR_b / afs \tag{A1.7}$$

A1.4.2.4 The angle of penetration of the IQI shall be 90° (±1.5°).

A1.4.2.5 It shall be assured that the size inside the hole profile is in minimum four times larger than the size of the unsharpness of the edge profile. Additionally the diameter of the hole in the image shall be more than 100 pixels.

A1.4.3 An image shall be captured. The SNR shall be larger than 100 in the image on the IQI beside the 4T hole.

A1.4.3.1 If the SNR is larger than 300 a digital magnification of factor two with a bilinear (or higher degree) interpolation between the pixel may be used.

A1.4.4 The pixel size in the image shall be calibrated by a known object size in the image for example, the IQI dimension of the plate or of the 4T hole. The precision of calibration shall be 1/100 of the hole diameter.

A1.5 Evaluation

A1.5.1 *Manual Evaluation Using a Line Profile:*

A1.5.1.1 A line profile shall be drawn in horizontal direction and it shall be averaged over in minimum 5 pixel or the width of 1/20 of the hole diameter.

A1.5.1.2 A marker shall be set at 50 % (±2 %) of the signal inside the hole. A second marker shall be placed at a position of 34 % more signal compared to the first marker with same tolerance (84 % ± 2 %). The distance between both markers shall be noted (in real units or in pixels). A third marker shall be set at the opposite side of the IQI hole at 50 % (±2 %) and a fourth at a position of 34 % more signal compared to the third marker with same tolerance (84 % ± 2 %). The distance between both markers shall be noted as before; see Fig. A1.2 for an example. The values of the first distance difference and the second distance difference shall be summed.

A1.5.1.3 The evaluation for the vertical direction shall be done in the same manner.

A1.5.1.4 The values are measured from 50 % to 84 %; to extrapolate to 100 % both values shall be multiplied by the factor of 1.4 (Note A1.1).

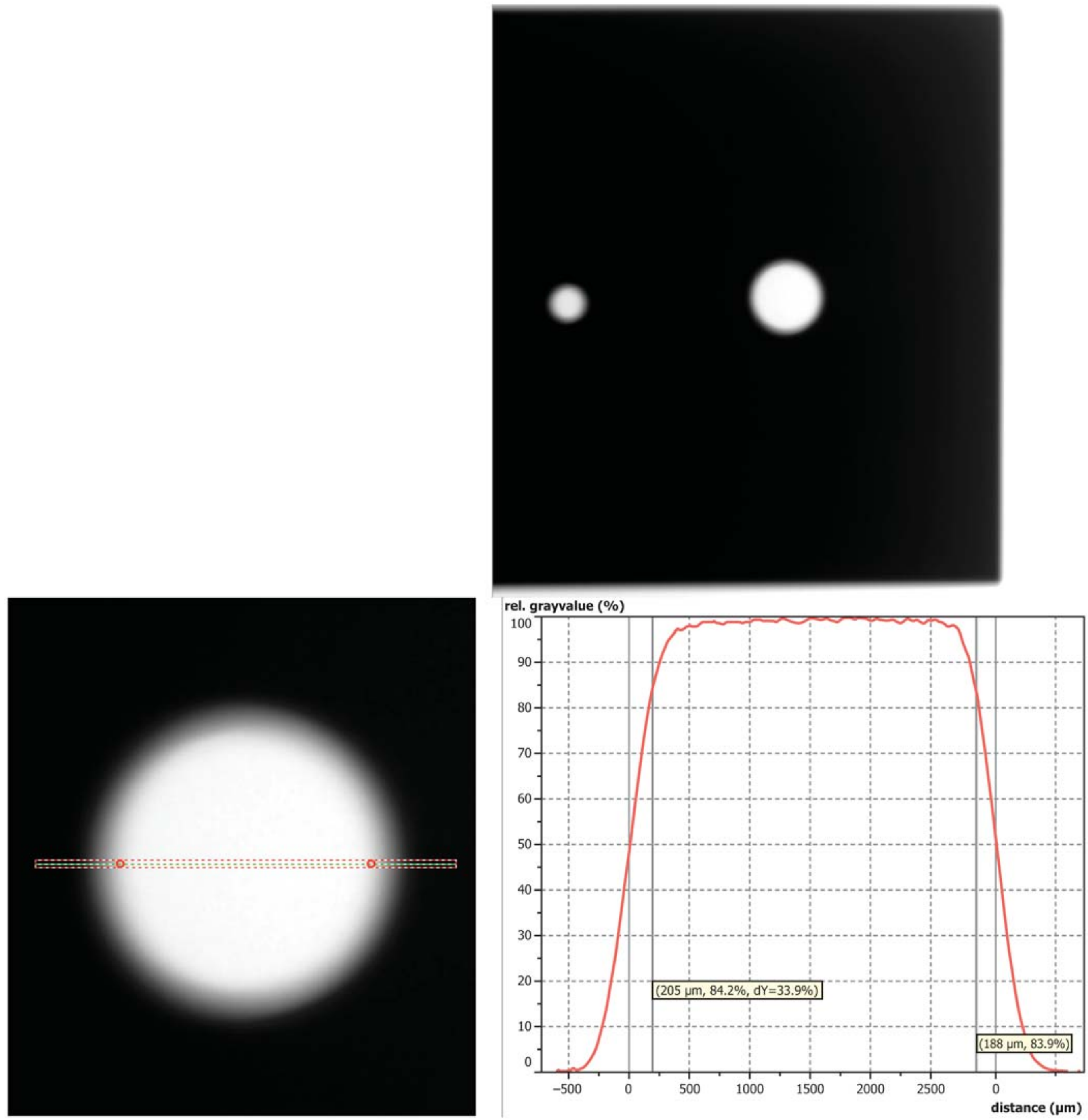
NOTE A1.1—To compensate the bias of about 5 % higher values the extrapolation factor is reduced from 1.47 to 1.4. The bias is caused by the fact that the edges are not in the center of the beam and therefore the X-rays do not penetrate it at a 90 degree angle.

A1.5.1.5 The resulting unsharpness still contains the unsharpness due to the detector. Therefore the results have to be corrected using Eq A1.5 in A1.2 to calculate the effective focal spot size.

A1.5.1.6 The corrected values of the effective focal spot size shall be assigned to the X or Y direction of the X-ray tube (depending on the orientation of the tube in the X-ray system; see Fig. 7 for the assignment).

A1.5.2 *Automatic Evaluation Using a Software Function:*

A1.5.2.1 A Region of Interest (ROI) shall be drawn around the hole with about double the diameter of the hole. The calibration of the pixel size shall be done by entering the hole size in real units, the pixel size and the detector resolution SR_b. The software shall calculate the calibration value by using the 50 % signal level threshold in both horizontal and vertical direction. Then the software shall evaluate the unsharpness on the four edges in vertical and horizontal direction using 50 % and 84 % thresholds. The values of the two edges for vertical unsharpness shall be summed and the same shall be done for the horizontal direction. The results shall be extrapolated to



NOTE 1—Correction with detector unsharpness and the extrapolation factor of 1.4 shall be applied for final calculation of the effective focal spot size.

NOTE 2—The effective focal spot size of the example shown in Fig. A1.2 is 550 µm in horizontal direction.

NOTE 3—The measurement is performed in analogy to the method of measurement of micro focus spot sizes of EN 12543-5.

FIG. A1.2 Measurement of the Focal Spot Size from the Horizontal Edge Profile with Thresholds of 50 % to 84 % on Both Sides of the Line Profile

100 % with the extrapolation factor of 1.4 (Note A1.1) and then corrected for the detector unsharpness using the correction Eq A1.5 from A1.2 within the software.

A1.5.2.2 The results shall be recorded; it may also be displayed in the image (see Fig. A1.3) or written in a result file.

A1.5.2.3 The resulting values shall be assigned to the X or Y direction of the x-ray tube (depending of the orientation of the tube in the x-ray system; see Fig. 7 for the assignment).

FIG. A1.3 Measurement of the Spot Size of the Four Edges with Threshold from 50 % to 84 % and Extrapolation with Factor 1.4 with Automatic Calculation of the Effective Focal Spot Size in X and Y Direction

A1.6 Report

A1.6.1 If one value is needed as effective focal spot size only, the maximum of the horizontal or vertical value shall be taken as the result of the test.

A1.7 Precision and Bias

A1.7.1 *Statement of Precision:*

A1.7.1.1 A test report in accordance with ASTM E691 was repeated with the tube of the reliability test of 9.1 using different positions of the IQI. The automatic evaluation with the software function was used. The parameter were 120 kV, 5.3 mA, Magnification 5.0, IQI hole size 3.05 mm (2T hole), pixel size 200 µm, SR_b = 230 µm, SNR = 420.

A1.7.1.2 The mean value of the length of the focal spot due to this method is 0.5406 mm and the width 0.5591 mm. The standard deviation is 0.017036 mm for the length and 0.008012 mm for the width (3.15 % and 1.43 %). In the ASTM E691 evaluation the external and internal consistency values are within the critical interval of 0.5 % significance level for focal spot length and width.

A1.7.1.3 Using the manual evaluation with the line profile the precision also depends on the exact position of the four markers in vertical and horizontal direction.

A1.7.2 *Statement on Bias:*

A1.7.2.1 As reference for the focal spot size the value of the ILP method was taken (see 9.1). The deviation of the user method to the reference values were –2.64 % for the length and 1.47 % for the width.

A1.7.2.2 Bias of the user method is produced by edge penetration of the IQI which may lead to larger values and the position of the IQI in length direction due to the steep angle of the target (see Fig. 1).