Designation: E2903 – 13

Standard Test Method for Measurement of the Effective Focal Spot Size of Mini and Micro Focus X-ray Tubes[1]

This standard is issued under the fixed designation E2903; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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 imaging place.

1.2 This test method provides instructions for determining the effecting size (dimensions) of mini and micro focal spots of industrial X-ray tubes. It is based on the European standard, 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.

1.3 This standard specifies a method for the measurement of effective focal spot dimensions from 5 up to 300 µm of X-ray systems up to and including 225 kV tube voltage, by means of radiographs of edges. Larger focal spots should be measured using Test Method E1165 Standard Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging.

1.4 The same procedure can be used at higher kilovoltages by agreement, but the accuracy of the measurement may be poorer.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this 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]

E1165 Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging
E1255 Practice for Radioscopy
E1742 Practice for Radiographic Examination
E1815 Test Method for Classification of Film Systems for Industrial Radiography
E2002 Practice for Determining Total Image Unsharpness in Radiology
E2033 Practice for Computed Radiology (Photostimulable Luminescence Method)
E2446 Practice for Classification of Computed Radiology Systems
E2597 Practice for Manufacturing Characterization of Digital Detector Arrays
E2698 Practice for Radiological Examination Using Digital Detector Arrays

2.2 *European Standards:*[3]

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

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.

3.1.2 *effective focal spot*—the X-ray producing area of the target as viewed from the image plane.

[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 1, 2013. Published June 2013. DOI: 10.1520/E2903–13.

[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 American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

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4. Summary of Test Method

4.1 This method is based on indirect measurement of the focal spot size by measuring the geometric unsharpness then using a geometric calculation to determine the effective focal spot dimensions (see Section 8). For this purpose, edges are imaged either on a film or by means of a radioscopic or digital radiographic device using a relatively high geometric magnification. For a full description see reference below.[4]

5. Significance and Use

5.1 One of the factors affecting the image quality of a radiographic image is geometric unsharpness. The degree of geometric unsharpness is dependent upon the focal spot size of the radiation source, the distance between the source and the object to be radiographed, the distance between the object to be radiographed and the image plane (film, imaging plate, Digital Detector Array (DDA), or radioscopic detector). This test method allows the user to determine the effective focal spot size (dimensions) of the X-ray source. This result can then be used to establish source to object and object to image detector distances appropriate for maintaining the desired degree of geometric unsharpness or maximum magnification possible, or both, for a given radiographic imaging application. The accuracy of this method is dependent upon the spatial resolution of the imaging system, magnification, and signal-to-noise of the resultant images.

6. Apparatus

6.1 The following equipment is required for the measurement if using X-ray film:

6.1.1 A test object as described in 6.5.

6.1.2 X-ray films, without screens, of sufficient size to image magnified test object and region around test object to obtain a profile as shown in Fig. 1.

6.1.3 Film cassettes made of low absorbing material (for example polyethylene).

6.1.4 A film holder.

6.1.5 A film processing unit.

6.1.6 A film scanner capable of reading densities greater than 3.0 configured such that the pixel size is appropriate for the measurement (refer to Section 7). The film shall be of sufficient size to image the magnified test object and region around test object to obtain a profile as shown in Fig. 1.

6.1.7 The film system shall meet the requirements of Test Method E1815 film system class I, II, or Special.

6.2 The following equipment is required for the measurement if using computed radiography (CR):

6.2.1 A test object as described in 6.5.

6.2.2 A computed radiography system, consisting of an imaging plate and scanner, configured such that the pixel size is appropriate for the measurement (refer to Section 7). The imaging plate shall be of sufficient size to image test object and region around test object to obtain a profile as shown in Fig. 1.

6.2.3 The computed radiography system shall meet the requirements of Practice E2446 class I, II, or Special, and image plates shall be packed in low absorption cassettes using no screens.

[4] Fry, Ewert, Gollwitzer, Neuser, and Selling, "Measuring microfocal spots using digital radiography"*Materials Evaluation,*, Vol 70, No.8, August 2012, p. 981.

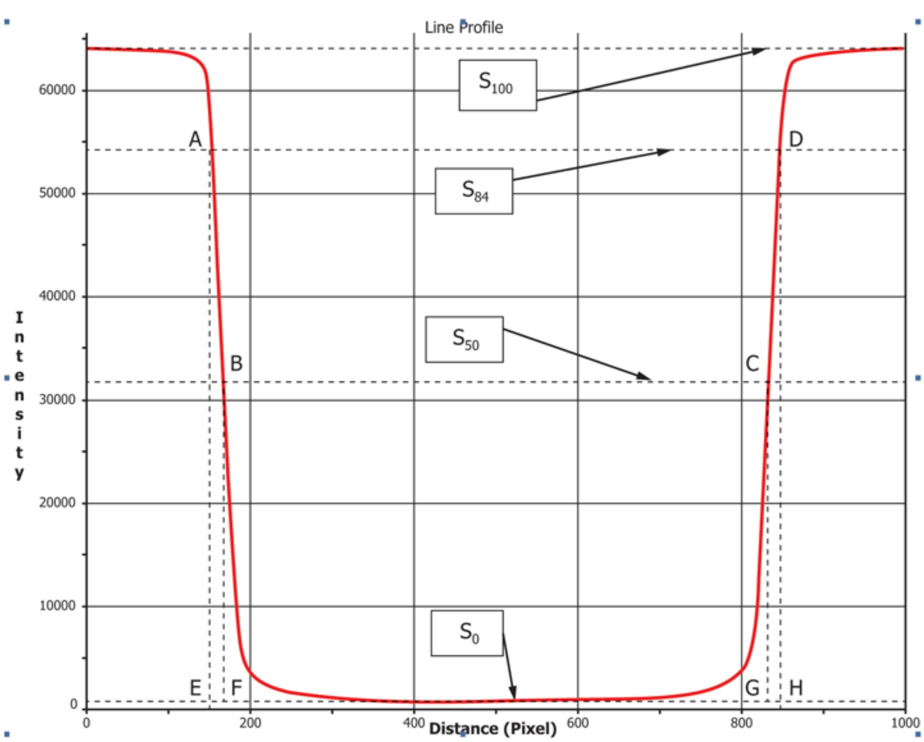

FIG. 1 Profile of Test Object Image (Test Object: Pt wire 1 mm)

6.3 The following equipment is required for the measurement if using a radioscopic or digital detector array device:

6.3.1 A test object as described in 6.5.

6.3.2 A radioscopic device, for example any image intensifier with video equipment or Digital Detector Array, configured such that the pixel size is appropriate for the measurement (refer to Section 7), or

6.3.3 A Digital Detector Array system meeting the requirements of Practice E2597. The digital Detector Array cover should be constructed of low X-ray absorption material and should be free of cluster kernel pixels as defined in Practice E2597.

6.3.4 The imaging area shall be of sufficient size to image magnified test object and region around test object to obtain a profile as shown in Fig. 1.

6.4 Image processing equipment as follows:

6.4.1 An image processing device with the capability of producing linearized intensity profiles (signal is linear with dose), integration of profiles, and profile plots within the digital image in two directions perpendicular to each other, and with the capability to measure distances.

6.5 The test object shall be either a set of wires or a sphere consisting of highly absorbing material (for example tungsten, tungsten alloy, or platinum). The diameter of the wire or sphere should be greater than 20 times the focal spot dimension if the focal spot is less than 40 µm to minimize edge penetration; otherwise, the diameter should be 0.8 to 1.0 mm for focal spots greater than 40 µm. The diameter shall be known to within ±1 %.

6.5.1 In case of using two single crossed wires they shall cross each other at an angle of 90° ± 3°. The wires shall be mounted across a circular aperture in a stable frame, in such a manner that the crossing point is located in the center of the aperture. In case of using the sphere it shall be mounted on a thin polyethylene support or placed into a thin polyethylene envelope.

6.5.2 The Unsharpness Gauge of Practice E2002 is recommended as a test object of defined accuracy. Two exposures shall be taken with the wire set in perpendicular directions to obtain the length and width of the focal spot.

6.5.3 The mounting frame shall be of a size that enables the test object to be positioned very close to or on the window of the X-ray tube.

7. Procedure

7.1 Any use of additional X-ray pre-filtering should be avoided.

7.2 The X-ray voltage (in kV) should not exceed ten times the focal spot size in µm for precise measurements of focal spots below 20 µm.

7.3 Image capture requirements:

7.3.1 The distance between test object and detector shall enable projective magnification (see Fig. 2), where smaller focal spots require larger magnification.

7.3.2 Precision is dependent upon the spatial resolution of the imaging system, magnification, and signal-to-noise of the resultant images (See Footnote 4). If an estimate of the focal spot size, s, is available, then an optimal magnification can be computed:

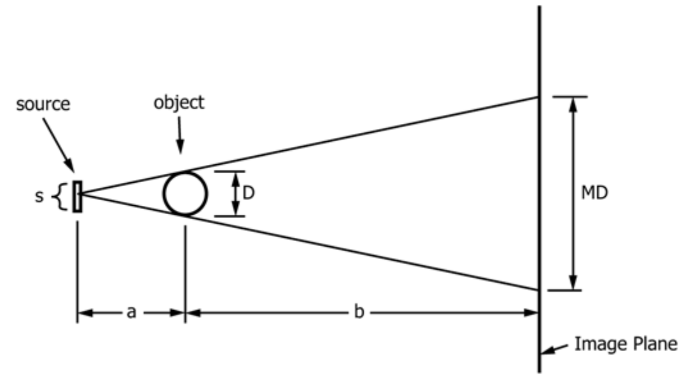

FIG. 2 Positioning of Test Object

$$M_{optimal} = 1 + 1.1\ SNR\ (P/\ s_{optimal}) \quad (1)$$

where:

SNR = unattenuated Signal-to-Noise ratio outside the object
P = pixel size

7.3.2.1 If the actual magnification is less than or equal to $M_{optimal}$, then the estimated precision is:

$$Precision_{estimated} = 0.71\sqrt{[1/n\ (u1)]^2 + [1/n\ (u2)]^2} \times 100\% \quad (2)$$

where:

n(u1) = number of pixels across the 50 to 84 % profile on one side (E to F in Fig. 1)
n(u2) = number of pixels across the 50 to 84 % profile on the other side (G to H in Fig. 1)

7.3.2.2 If the actual magnification is greater than $M_{optimal}$, then the estimated precision is:

$$Precision_{estimated} = 2/SNR \times 100\% \quad (3)$$

7.3.2.3 In many cases the optimal magnification cannot be achieved due to the distance required. However, adequate precision may still be obtained by using lesser magnification. In general, the diameter of the test object image should be as large as possible within the active area of the imaging medium while leaving room to make profile measurements.

7.3.3 The minimum distance between the test object and the focal spot (distance "a" in Fig. 2) shall be at least five times the wire or sphere diameter.

7.3.4 In case of using a cross wire or Practice E2002 Unsharpness Gauge, its plane shall be parallel within ±3° to the detector plane and X-ray tube output window.

7.3.5 In case of using a film, the exposure time shall result in a background density outside the test object of the radiograph film of D = 2.5 ± 0.5. If no shutter is used, the exposure time shall exceed 30 seconds.

7.3.6 In the case of using computed radiography, a digital detector array, or a radioscopic device, the mean pixel value in the background image outside the test object should be ≥75 % of saturation for the system settings selected. When using a

DDA or radioscopic device, if the mean pixel value is less than 75 % of saturation, then frames may be added together to achieve ≥75 %.

7.3.7 Capture an image. Perform film radiography in accordance with Practice E1742. Operate computed radiography systems in accordance with Practice E2033. Operate DDA systems in accordance with Practice E2698. Operate radioscopy systems in accordance with Practice E1255. No image quality indicators are used.

7.3.8 If X-ray film is used, scan the film with a scanner as specified in 6.1.6 in accordance with the film scanner manufacturer instructions.

8. Calculation of Results

8.1 Line scans shall be produced of the image in length and width direction, see Fig. 1.

8.1.1 The measurement shall be made using an image processor in accordance with 6.5.1. Line averaging may be used to reduce noise if using wires or the Practice E2002 gauge ensuring that the wire aligns with the pixel matrix such that the wire edge image remains within one pixel width along the averaged section of the wire.

8.2 From these scans the imaging plane diameters D_W and D_L of the test object in width and length direction shall be measured at 50 % of the total image contrast (diameter is the distance between points F and G.) The length and width directions should be related back by geometry to the X-ray tube housing.

8.3 The geometrical magnification is shown in the following Eq 4

$$M_{L,W} = D_{L,W}/D_{real} \tag{4}$$

where:

D_{real} = the real diameter

8.4 In case of the crossed wires both wires have to be measured because of their different magnifications.

8.5 Referring to Fig. 2 and using simple geometry, the following equations are established

$$s/a = U/b \tag{5}$$

$$s = Ua/b = U/(M - 1) \tag{6}$$

U is the sum of the spatial distance between S_{50} and S_{84} on each side of ball or wire to average the focal spot effect on U. The outside half of the line profile is used to avoid additional unsharpness due to edge transmission.

$$U = \bar{EF} + \bar{GH} \tag{7}$$

8.6 Then, according to Fig. 1, the points A and D are obtained at 84 % of the contrast. From the projection the effective focal spot dimensions s_L and s_W are calculated using Eq 8 and Eq 9:

$$s_L = 1.47 \times (\bar{EF} + \bar{GH})/(M_L - 1) \tag{8}$$

$$s_W = 1.47 \times (\bar{EF} + \bar{GH})/(M_W - 1) \tag{9}$$

8.7 If the actual focal spot size differs appreciably from the estimated focal spot size, then the optimal magnification should be recalculated to determine if a more precise measurement can be made. See 6.2.2.

8.8 *Determination:*

8.8.1 Each focal spot size is defined by its dimensions—*L* (length) in the direction of the tube axis and its size *W* (width) in the perpendicular direction.

8.8.2 If the tube axis is not defined, then the direction of the electron trajectory shall be used instead.

8.8.3 For transmission target tubes, length and width shall be horizontal and vertical when looking at the X-ray tube from the image plane.

8.8.4 The larger of these sizes shall be used as the "focal spot size *s*" or can be reported as *L* x *W*. It is only valid in connection with the used and recorded operating parameters during the measurement.

8.9 A certificate of the measured focal spot size shall include the measurement conditions (tube energy, filters, and current, detector manufacturer and type, distances, film or CR system scanner parameters, and object type and diameter certification).

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 within a single laboratory.

9.1.2 If the actual magnification is less than or equal to $M_{optimal}$ (see Eq 1 in 7.3.2) then the repeatability standard deviation is:

$$\text{Repeatability} = 0.71\sqrt{[1/n(u1)]^2 + [1/n(u2)]^2} \times 100\ \% \tag{10}$$

where:

n(u1) = the number of pixels across the 50 to 84 % profile on one side

n(u2) = the number of pixels across the 50 to 84 % profile on the other side

9.1.3 If the actual magnification is greater than $M_{optimal}$ then the repeatability standard deviation is:

$$\text{Repeatability} = 2/\text{SNR} \times 100\% \tag{11}$$

9.1.4 The 95 % repeatability precision is 2.8 times the repeatability standard deviation.

9.2 *Statement on Bias:*

9.2.1 Bias is produced by edge penetration of the test object (see Footnote 4). If care is taken to minimize edge penetration using the recommendation in 6.5, then bias should be less than 2 µm.

10. Keywords

10.1 focal spots; microfocus; X-ray imaging; X-ray tube

11. Rationale

11.1 Measurement of microfocus spot size can be important for several reasons:

11.1.1 Quality assurance during manufacture of microfocus tubes.

11.1.2 Tracking performance and stability of microfocus tubes.

11.1.3 Determining maximum possible magnification for an inspection (especially important for digital radiography where the native spatial resolution of the digital system is not adequate for the application).

11.1.4 Contribution to total unsharpness from the focal spot alone.

11.2 The European Standard EN 12543-5 is based on a simple geometrical method of calculating focal spot size from unsharpness of high magnification film radiographs. The focal spot size can be calculated by measuring the radiographic unsharpness and magnification of a known object. This is the basis for these tests. EN 12543-5 uses film as the image detector. This standard was developed to extend the method to digital radiographic image detection (computed radiography, digital detector arrays, and radioscopy).

11.3 See Footnote 4 for a full description of the background and development of this test method.

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