Designation: E2002 – 2015

Standard Practice for Determining Total Image Unsharpness and Basic Spatial Resolution in Radiography and Radioscopy[1]

This standard is issued under the fixed designation E2002; 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 This practice covers the design and basic use of a gauge used to determine the total image unsharpness and the basic spatial resolution of film radiographs or of digital images taken with CR imaging plates, digital detector arrays, or radioscopic systems.

1.2 This practice is applicable to radiographic and radioscopic imaging systems utilizing X-ray and gamma ray radiation sources.

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

1.4 The gauge described can be used effectively with tube voltages up to 600 kV. When using source voltages in the megavolt range the results may not be completely satisfactory.

1.5 *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]

E747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E1316 Terminology for Nondestructive Examinations

E1815 Test Method for Classification of Film Systems for Industrial Radiography

2.2 *ISO Standards*[3]

ISO 19232–1 Non-destructive Testing—Image Quality of Radiographs—Part 1: Image Quality Indicators (Wire Type)—Determination of Image Quality Value

ISO 19232–2 Non-destructive Testing—Image Quality of Radiographs—Part 2: Image Quality Indicators (Step/Hole Type)—Determination of Image Quality Value

ISO 19232–5 Non-destructive Testing—Image Quality of Radiographs—Part 5: Determination of Image Unsharpness Value Using Duplex Wire Type Image Quality Indicators

ISO/IEC 17050–1 Conformity Assessment—Supplier's Declaration of Conformity—Part 1: General Requirements

2.3 *CEN Standard:*

EN-462-5:1996 Nondestructive Testing—Image Quality of Radiographs—Part 5: Image Quality Indicators (Duplex Wire Type)—Determination of Total Image Unsharpness Value[4]

3. Terminology

3.1 *Definitions*—Definitions of terms applicable to this practice may be found in Terminology E1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *basic spatial image resolution (SR_b^{image}) value*—determined from the smallest number of the duplex wire pair, which is not separable by visual inspection or from the smallest number of the duplex wire pair with less than 20% modulation depth in a linearized profile, and corresponds to ½ ·U_T. U_T may be U_T^{visual} or $U_T^{20\%}$.

3.2.2 *duplex wire type image quality indicator*—duplex wire type image quality indicator (IQI) specifically designed to assess the total image unsharpness and basic spatial image resolution of a radiograph or a digital image and composed of a series of pairs of wire elements made of high density metal.

[1] This practice 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.

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[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 International Organization for Standardization (ISO), ISO Central Secretariat Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[4] Available from British Standards Institute (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsi-global.com.

3.2.3 *interpolated basic spatial image resolution (iSR_b^{image}) value*—determined from the modulation values of different neighbored duplex wire pairs by interpolation, which corresponds to ½ · $iU_T^{20\%}$.

3.2.4 *interpolated total image unsharpness ($iU_T = iU_T^{20\%}$)*—value determined from a profile function in a digital image by interpolation – is determined from a linearized profile function and obtained by interpolation to 20% modulation depth from neighbored element modulations.

3.2.5 *linepair per mm (lp/mm) value*—determined from the duplex wire pair values or the interpolated values, and corresponds to $1/U_T$. U_T may be U_T^{visual}, $U_T^{20\%}$, or $iU_T^{20\%}$.

3.2.6 *total image unsharpness ($U_T = U_T^{visual}$)*—determined visually—is determined from the smallest number of the duplex wire pair, which is visually not separable in a film radiograph on a viewing station or on a monitor image.

NOTE 1—The corresponding unsharpness values are given in Table 1.

3.2.7 *total image unsharpness ($U_T = U_T^{20\%}$)*—value, determined from a profile function in a digital image – is determined from the smallest number of the duplex wire pair, which is separable by a profile function with less than 20% modulation depth in a linearized profile.

4. Summary of Practice

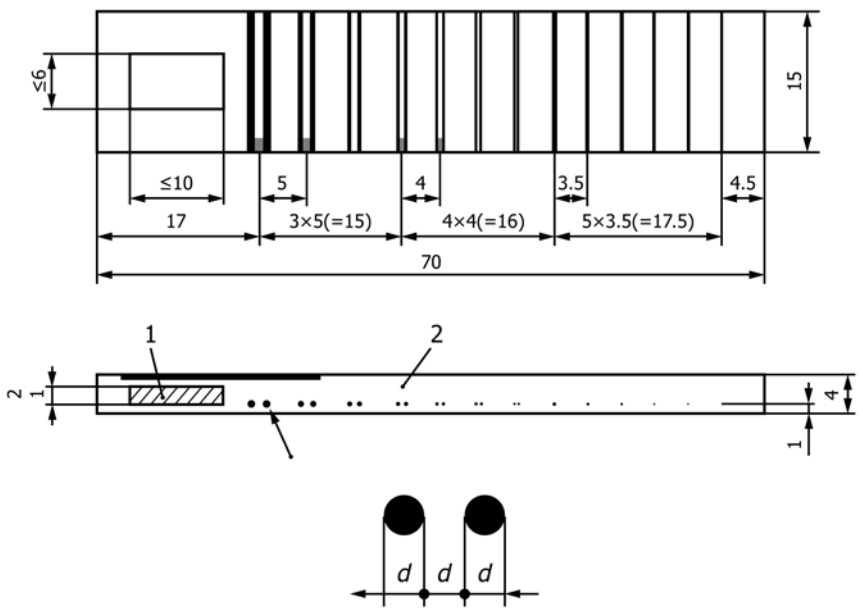
4.1 When it is determined necessary to evaluate and measure the total image unsharpness or the basic spatial resolution of an imaging system separately and apart from contrast sensitivity measurements, a tool or gauge as described in this practice can be used. Conventional IQIs as described in Practices E747 and E1025, or ISO 19232-1 and ISO 19232-2. Combine the contrast sensitivity and resolution measurements into an overall figure of merit. Such figures of merit may not be adequate to detect subtle changes in the imaging system's performance. For example, in a high-contrast image, unsharpness can increase with almost no noticeable effect upon the overall image contrast, but the contrast sensitivity for fine details will be reduced. Similarly, in an application in which the imaging system provides a very sharp image, contrast can fade with little noticeable effect upon the overall image contrast. These situations often develop and may go undetected until the system performance deteriorates below acceptable image quality limits.

5. Significance and Use

5.1 The gauge is intended to provide a means for measuring total image unsharpness and basic spatial image resolution as independently as practicable from the imaging system contrast sensitivity limitations. A similar description of the gauge's construction may be found in ISO 19232-5. When the duplex gauge is positioned directly on the film or the digital detector without any test object between them, the total image unsharpness or basic spatial image resolution is equivalent to the inherent film or detector unsharpness (U_i) and the basic spatial detector resolution ($SR_b^{detector}$). Alternatively, line pair gauges with constant bar thickness of high attenuating material can be used to determine total image unsharpness and basic spatial resolution of radiologic imaging systems. They may produce different results up to one wire pair as compared to duplex wire measurements as described in this standard.

6. Gauge Construction

6.1 The standard duplex wire IQI shall be fabricated in accordance with Fig. 1, using the tolerances given in Table 1.



NOTE 1—Not to Scale.

1 space for identification marking
2 rigid plastic mounting
wire diameter (d) equals spacing between the wires

FIG. 1 Total Image Unsharpness Gauge (see ISO 19232-5: 2013)

TABLE 1 Duplex Wire Number, Corresponding Total Unsharpness, Basic Spatial Resolution, Linepair Readings, and Wire Diameters and their Tolerances[A]

Wire Material	Duplex Wire Number	Corresponding Unsharpness Value (U_T) (mm)	Corresponding Basic Spatial Resolution SR_b Value (mm)[D]	Corresponding Linepair Value (lp/mm)	Wire Diameter and Spacing, d (mm)	Tolerance of Wire Diameter and Wire Spacing (mm)
Pt[B]	D13	0.10	0.050	10.0	0.05	
Pt	D12	0.13	0.063	7.94	0.063	
Pt	D11	0.16	0.080	6.25	0.08	±0.005
Pt	D10	0.20	0.100	5.00	0.10	
Pt	D9	0.26	0.130	3.85	0.13	
Pt	D8	0.32	0.160	3.13	0.16	
Pt	D7	0.40	0.200	2.50	0.20	
Pt	D6	0.50	0.250	2.00	0.25	±0.01
Pt	D5	0.64	0.320	1.56	0.32	
Pt	D4	0.80	0.400	1.25	0.40	
W[C]	D3	1.00	0.500	1.00	0.50	
W	D2	1.26	0.630	0.79	0.63	±0.02
W	D1	1.60	0.800	0.63	0.80	

[A] This table is based on data provided in ISO 19232-5:2013. All unsharpness values are rounded to two decimal places.
[B] Pt = Platinum.
[C] W = Tungsten.
[D] For conversion of the SR_b-values to µm, multiply values which are given in mm by 1000.

This gauge is identical to that described in ISO 19232-5: 2013, and if necessary, ISO 19232-5: 2013 may be reviewed for additional information.

6.2 The gauge shall consist of 13 elements. Each element shall consist of a pair of wires with circular cross-section. Elements 1 through 3 are of tungsten material and elements 4 through 13 are of platinum material. The 13 elements are mounted in a rigid plastic holder. Gauges with more elements than 13 can be used (see Section 8). These shall be used if unsharpness values lower than 0.1 mm or basic spatial resolution values lower than 0.05 mm need to be determined (see Sections 7 and 8).

6.3 The gauge shall be identified by marking "ISO D (or ISO 19232-5 or ASTM E2002) and a serial number." Marking shall be performed by any suitable means. IQIs with the letters "EN D (or EN 462-5)" are considered to be identical to IQIs with the letters "ISO" or "ASTM."

6.4 The gauge manufacturer shall provide a certificate of conformance with each gauge. Each IQI should be delivered with a declaration of conformity according to ISO/IEC 1750-1. For identification, the IQI should be numbered and marked by the producer.

7. Application

7.1 A radiograph shall be made or an image displayed on a monitor with the duplex wire placed on the source side of the item being examined or the gauge may be placed on a block representing the material and total thickness of the item being examined. The duplex wire IQI should be aligned, as closely as possible, normal to the axis of the radiation beam.

NOTE 2—If the IQI is placed directly on the detector, the inherent detector unsharpness and $SR_b^{detector}$ is measured.

7.2 The evaluation of the duplex wire pair images are based on a visual evaluation by an operator of films on a viewing station or images on a monitor, or by measurement with a profile function if digital images are available. The total image unsharpness U_T is given as $2d$, where d is the corresponding diameter of the duplex wires and is also the wire spacing distance (see Fig. 1). The value of d is considered as the basic spatial resolution of the image. The term $1/(2d)$ is considered as linepair/mm value.

7.2.1 *Visual Evaluation*—The image of the duplex wire IQI shall be examined using magnification up to 4 × on film or on a monitor. For evaluation of D12 and higher on films, a magnification lens > 2 × shall be used. The element with smallest wire number, (that is pair of wires), of which the image has just merged into single form without an identifiable space between the images of the two wires, is taken as the limit of visual discernibility for radiography and radioscopy.

NOTE 3—Visual determination of the first unresolved wire pair may depend on the contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) for digital systems or radioscopic systems, or may depend on the film system class and tube kV. Therefore, the visual evaluation of reference images should be performed at CNR or SNR values (for digital systems) or using the film system class and kV values typically used for the production radiographs.

7.2.2 *Evaluation of Digital Images with Profile Function*—If digital images are evaluated with a profile function, the element with smallest wire number, of the duplex wire pair, which is separable by a profile function with less than 20% modulation depth, is taken as the limit of discernibility for digital radiography. See Fig. 2. The profile function shall be evaluated from linearized pixel profiles.

7.2.2.1 The duplex wire IQI shall be positioned at an angle of approximately 2° to 5° towards the pixel line or column orientation as shown in Fig. 2a in order to reduce aliasing effects in the digital images.

7.2.2.2 The total unsharpness or the basic spatial resolution of digital images is based on the determination of the first duplex wire pair (smallest number) with less than 20% modulation depth (dip).

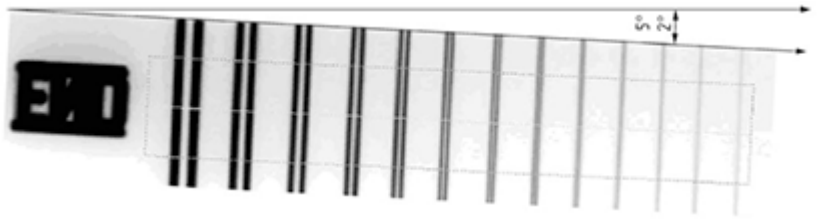


FIG. 2 Wire-pair Image Analysis for Calculation of Basic Spatial Resolution (SR_b) and Total Unsharpness (U_T) of Digital Images. The lowest wire pair value shall be determined which has a modulation depth (dip) < 20%. The modulation depth is determined in the profile function as shown in Fig. 2c-d. The first "unsharp" wire pair in Fig. 2c is D8. The resulting values are corresponding to Table 1: SR_b = 0.16 mm and U_T = 0.32 mm.

(a) Image of Duplex Wire IQI as Shown in a Digital Radiograph with Indicated Profile Line and its Integration Window

NOTE 1—Digitized films and CR images are typically presented and acquired in negative presentation. These images and their line profile plots will be inverted compared to the examples shown (i.e. white = more dense material).

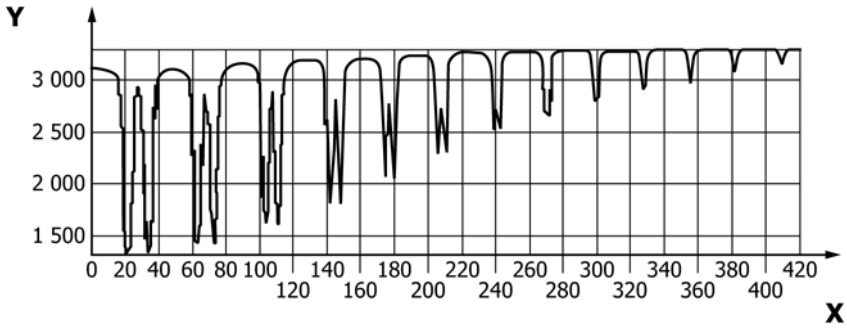


FIG. 2 (b) Profile of a Duplex Wire IQI, Averaged from Profile Lines, Covering 30–60% of the Wire Length. X = distance, Y = amplitude. *(continued)*

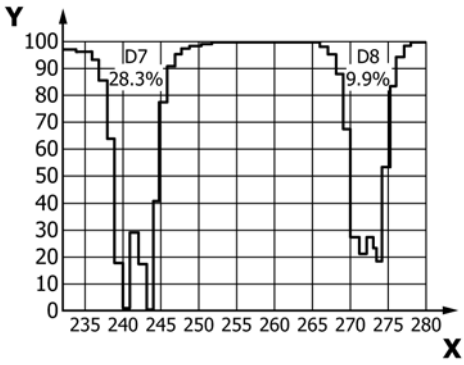


FIG. 2 (c) Zoomed Profile of Wire Pair D7 and D8. X = distance, Y = amplitude. *(continued)*

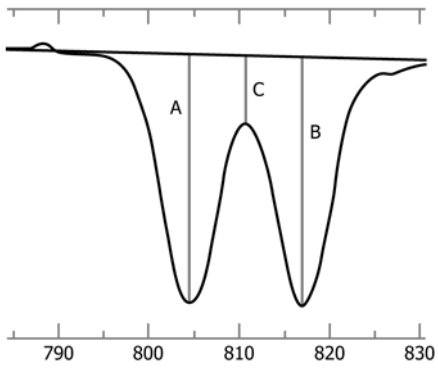


FIG. 2 (d) Scheme of the Calculation of the Dip Value in % with Dip = 100*(A+B-2c)/(A+B) *(continued)*

7.2.2.3 The measurement shall be done with a profile function of an image processing software across the middle area of the IQI image integrating along the wires of about 30-60% of the duplex wires' length in order to obtain a robust repeatable value, but shall use a minimum of an 11 pixel width line profile (or the average of 11 single width line profiles) to avoid variability along the length of the wires (Fig. 2b).

7.2.3 *Evaluation of Digital Images with Profile Function by Interpolation*—For more accurate measurement of the total unsharpness (iU_T) or the basic spatial resolution of digital images (iSR_b) the measurement of the 20% modulation depth should be performed by interpolation or approximation. This may be required for manufacturer qualification or if specified by contracting parties. See Fig. 3. The profile function shall be evaluated from linearized pixel profiles.

7.2.3.1 The duplex wire IQI shall be positioned at an angle of approximately 2° to 5° towards the pixel line or column orientation as shown in Fig. 2a in order to reduce aliasing effects in the digital images.

7.2.3.2 The measurement shall be done with a profile function of an image processing software across the middle area of the IQI image integrating along the wires of about 30 to 60 % of the duplex wires' length in order to obtain a robust repeatable value, but shall use a minimum of an 11 pixel width line profile (or the average of 11 single width line profiles) to avoid variability along the length of the wires (Fig. 3a-b).

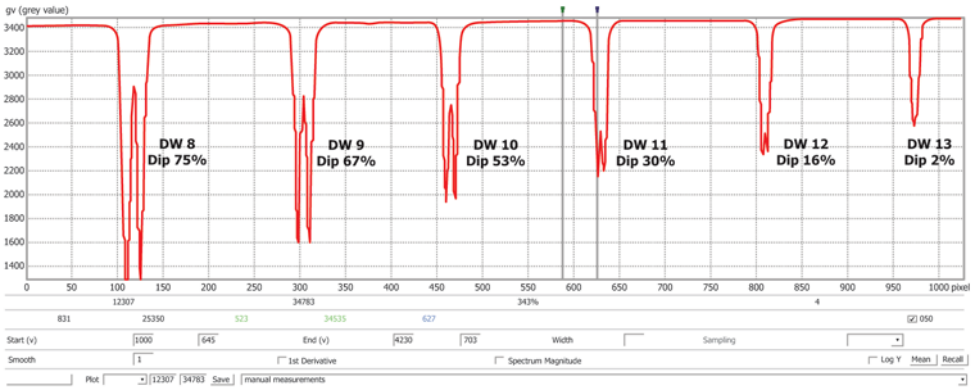


FIG. 3 Wire Pair Image Analysis for Calculation of Interpolated Basic Spatial Resolution (iSR_b^{image}) and Interpolated Total Unsharpness (U_T) of Digital Images with $iU_T = 2 \cdot iSR_b^{image}$
(a) Profile Plot of a Measured Profile of a High-Resolution System with Determined Modulation Depth (Dip)

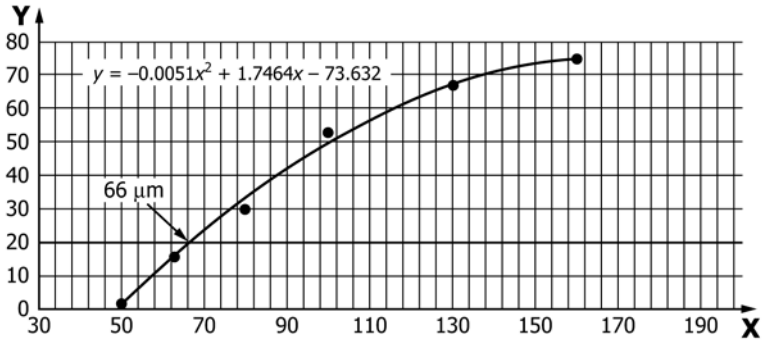


FIG. 3 (b) Approximation of Modulation Depth vs. Duplex Wire Pair Spacing. The 20 % Value is Determined from the Intersection with the 20 % Line Resulting in iSR_b = 0.066 mm and iU_T = 0.132 mm. *(continued)*

7.2.3.3 For improved accuracy in the measurement of the iU_T and the iSR_b value, the 20 % modulation depth (dip) value shall be approximated from the modulation depth (dip) values of the neighbor duplex wire modulations. Fig. 3 visualizes the corresponding procedure.

7.2.3.4 The iSR_b is calculated as the polynomial approximation of the modulation depth (dip) vs. the wire pair spacing of neighbored wire pairs with at least two wire pairs with more than 20 % dip between the wires in the profile and at least two wire pairs with less than 20 % dip between the wires in the linearized profile (see Fig. 3), if their values are larger than zero. If no values are available with dip < 20 %, the next wire pair value with the dip of zero shall be used. If the measured iSR_b is smaller than the pixel size, e.g. due to aliasing effects, iSR_b shall be qualified as iSR_b = pixel size. The interpolated total unsharpness (iU_T) is calculated from iSR_b by:

$$iU_T = 2 \cdot iSR_b \quad (1)$$

7.2.3.5 The resulting approximated or interpolated basic spatial resolution value (see Fig. 3b) shall be documented as "interpolated SR_b-value" or iSR_b. The resulting approximated or interpolated total unsharpness value shall be documented as "interpolated UT-value" or iU_T.

NOTE 4—The dependence of modulation depth (dip) from wire pair spacing should be fitted with a polynomial function of second order for calculation of the intersection with the 20 % line as indicated in Fig. 3b.

7.3 Performance levels of unsharpness of images or detectors are relative to the user's applications and shall be specified in the purchaser/supplier agreement or in reference to standard practices.

7.4 The duplex wire gauge may be applied to monitor the geometric unsharpness (U_g), the total unsharpness (U_T), the image unsharpness (U_{im}) and basic spatial resolution (SR_b^{image}) in radiographic images. It may be used for reference exposures to determine the inherent unsharpness (U_i) of film screen systems or radioscopic systems, or the basic spatial resolution ($SR_b^{detector}$) of digital detectors.

NOTE 5—The duplex wire IQI is not an alternative gauge for the wire, plate/hole or step/hole type IQI because it relates only to unsharpness.

8. High Resolution IQI with Increased Measurement Range

8.1 For special applications it may be required to measure lower unsharpness values than those given in Fig. 1 and Table 1. Therefore, alternative high resolution duplex wire IQIs (HR Duplex Wire IQIs) may be used with more than 13 wire pairs.

8.2 These IQIs shall be constructed as described in the example scheme of Fig. 4, which describes a HR-IQI with 15 wire pairs. A larger gap of 5 mm is required between the 13th and 14th wire pair to enable the operator a reliable recognition

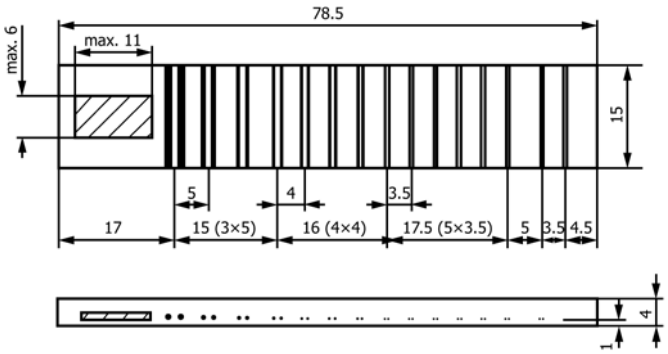


FIG. 4 High Definition Total Image Unsharpness Gauge with 15 Wire Pairs

TABLE 2 High Resolution Duplex Wire Number, Corresponding Total Unsharpness, Basic Spatial Resolution, Linepair Readings, and Wire Diameters and their Tolerances[C]

Wire Material	Duplex Wire Number	Corresponding Unsharpness Value (U_T) (mm)	Corresponding Basic Spatial Resolution SR_b Value (mm)[B]	Corresponding Linepair Value (lp/mm)	Wire Diameter and Spacing, d (mm)	Tolerance of Wire Diameter and Wire Spacing (mm)
Pt[A]	D18	0.032	0.016	31.1	0.016	
Pt	D17	0.040	0.020	25.0	0.020	
Pt	D16	0.050	0.025	20.0	0.025	±15%
Pt	D15	0.063	0.032	15.9	0.032	
Pt	D14	0.080	0.040	12.5	0.040	

[A] Pt = Platinum.
[B] For conversion of the SR_b-values to µm, multiply values which are given in mm by 1000.
[C] The parameters for wire pairs D1 through D13 are given in Table 1.

of the higher wire pair values. HR IQIs can have more than the 15 wire pairs as shown in Fig. 4.

8.3 Table 2 provides information about the corresponding HR IQI construction requirements of the wire pairs and the corresponding readings of U_T, SR_b and *lp/mm* for the HR IQI wire pairs with up to 18 wire pairs.

NOTE 6—Duplex wire IQIs with more than 13 wire pairs for readings of higher than D13 may be applicable at lower X-ray tube voltages than 225 kV only. This depends on the properties of the test objects. Users should take test exposures to verify the suitable application and kV range.

9. Records

9.1 The results of the image unsharpness measurement or the basic spatial resolution measurement should be recorded along with the imaging parameters, and maintained as a part of the initial qualification and performance monitoring records for the imaging system. Changes in image unsharpness or the basic spatial resolution can be an early indicator of deteriorating imaging system performance.

10. Precision and Bias

10.1 If the determination of the unsharpness or basic spatial resolution value is based on a visual evaluation by an operator on film or on monitor, the precision amounts to ± 1 duplex wire numbers at X-ray voltages below 450 kV for wire pair numbers D1 to D13 and film system classes "Special" or T1 – T2 (Test Method E1815). The IQI reading scatters typically between two neighbored duplex wire numbers if different operators do the evaluation. No statement is made about the precision and bias for film application of X-ray tube voltages > 450 kV.

10.2 Digital images should be taken with high contrast-to-noise ratio for the wire pairs to enhance the visibility of the wire pairs. The procedure of 7.2.2 improves the precision compared to the visual evaluation. The procedure of 7.2.2 provides a precision of ± 0.5 duplex wire numbers if the contrast-to-noise ratio of the evaluated wire pair is CNR > 20 in the integrated profile line. This means that the IQI reading scatters typically between two neighboring duplex wire numbers if different operators do the evaluation.

10.3 No statement is made about the precision and bias for determination of the interpolated total image unsharpness or the interpolated basic spatial resolution of an imaging system using the duplex wire IQI as described in the procedure of 7.2.3.

11. Keywords

11.1 basic spatial resolution; imaging system; gamma ray; line pairs per mm; radiation; total unsharpness; x-ray