Designation: E2737 – 10

Standard Practice for Digital Detector Array Performance Evaluation and Long-Term Stability[1]

This standard is issued under the fixed designation E2737; 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 describes the evaluation of DDA systems for industrial radiology. It is intended to ensure that the evaluation of image quality, as far as this is influenced by the DDA system, meets the needs of users, and their customers, and enables process control and long term stability of the DDA system.

1.2 This practice specifies the fundamental parameters of Digital Detector Array (DDA) systems to be measured to determine baseline performance, and to track the long term stability of the DDA system.

1.3 The DDA system performance tests specified in this practice shall be completed upon acceptance of the system from the manufacturer and at intervals specified in this practice to monitor long term stability of the system. The intent of these tests is to monitor the system performance for degradation and to identify when an action needs to be taken when the system degrades by a certain level.

1.4 The use of the gages provided in this standard is mandatory for each test. In the event these tests or gages are not sufficient, the user, in coordination with the cognizant engineering organization (CEO) may develop additional or modified tests, test objects, gages, or image quality indicators to evaluate the DDA system. Acceptance levels for these ALTERNATE tests shall be determined by agreement between the user, CEO and manufacturer.

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]

E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology
E1316 Terminology for Nondestructive Examinations
E1742 Practice for Radiographic Examination
E2002 Practice for Determining Total Image Unsharpness in Radiology
E2445 Practice for Performance Evaluation and Long-Term Stability of Computed Radiography Systems
E2597 Practice for Manufacturing Characterization of Digital Detector Arrays
E2698 Practice for Radiological Examination Using Digital Detector Arrays
E2736 Guide for Digital Detector Array Radiology

3. Terminology

3.1 *Definitions*—the definition of terms relating to gamma and X-radiology, which appear in Terminology E1316, Practice E2597, Guide E2736, and Practice E2698 shall apply to the terms used in this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *digital detector array (DDA) system*—an electronic device that converts ionizing or penetrating radiation into a discrete array of analog signals which are subsequently digitized and transferred to a computer for display as a digital image corresponding to the radiologic energy pattern imparted upon the input region of the device. The conversion of the ionizing or penetrating radiation into an electronic signal may transpire by first converting the ionizing or penetrating radiation into visible light through the use of a scintillating material.

[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.

These devices can range in speed from many seconds per image to many images per second, up to and in excess of real-time radioscopy rates (usually 30 frames per seconds).

3.2.2 *active DDA area*—the active pixelized region of the DDA, which is recommended by the manufacturer as usable.

3.2.3 *signal-to-noise ratio (SNR)*—quotient of mean value of the intensity (signal) and standard deviation of the intensity (noise). The SNR depends on the radiation dose and the DDA system properties.

3.2.4 *contrast-to-noise ratio (CNR)*—quotient of the difference of the signal levels between two material thicknesses, and standard deviation of the intensity (noise) of the base material. The CNR depends on the radiation dose and the DDA system properties.

3.2.5 *contrast sensitivity*—recognized contrast percentage of the material to examine. It depends on 1/CNR.

3.2.6 *spatial resolution (SR)*—the spatial resolution indicates the smallest geometrical detail, which can be resolved using the DDA with given geometrical magnification. It is the half of the value of the detector unsharpness divided by the magnification factor of the geometrical setup and is similar to the effective pixel size.

3.2.7 *material thickness range (MTR)*—the wall thickness range within one image of a DDA, whereby the thinner wall thickness does not saturate the DDA and at the thicker wall thickness, the signal is significantly higher than the noise.

3.2.8 *frame rate*—number of frames acquired per second.

3.2.9 *lag*—residual signal in the DDA that occurs shortly after detector read-out and erasure.

3.2.10 *burn-in*—change in gain of the scintillator that persists well beyond the exposure.

3.2.11 *bad pixel*—a pixel identified with a performance outside of the specification range for a pixel of a DDA as defined in Practice E2597.

3.2.12 *five-groove wedge*—a continuous wedge with five long grooves on one side (see Fig. 1).

3.2.13 *phantom*—a part or item being used to quantify DDA characterization metrics.

3.2.14 *duplex plate phantom*—two plates of the same material; Plate 2 has same size in x- and half the size in v- direction of Plate 1; the thickness of Plate 1 matches the minimum thickness of the material for inspection; the thickness of Plate 1 plus Plate 2 matches the maximum thickness of the material for inspection (see Fig. 2).

3.2.15 *DDA offset image*—image of the DDA in the absence of x-rays providing the background signal of all pixels.

3.2.16 *DDA gain image*—image obtained with no structured object in the x-ray beam to calibrate pixel response in a DDA.

3.2.17 *calibration*—correction applied for the offset signal and the non-uniformity of response of any or all of the X-ray beam, scintillator, and the read out structure.

3.2.18 *gray value*—the numeric value of a pixel in the DDA image. This is typically interchangeable with the term pixel value, detector response, Analog-to-Digital unit and detector signal.

3.2.19 *saturation gray value*—the maximum possible usable gray value of the DDA after offset correction.

NOTE 1—Saturation may occur because of a saturation of the pixel itself, the amplifier, or digitizer, where the DDA encounters saturation gray values as a function of increasing exposure levels.

3.2.20 *user*—the user and operating organization of the DDA system.

3.2.21 *customer*—the company, government agency, or other authority responsible for the design, or end user, of the system or component for which radiologic examination is required, also known as the CEO. In some industries, the customer is frequently referred to as the “Prime”.

3.2.22 *manufacturer*—DDA system manufacturer, supplier for the user of the DDA system.

4. Significance and Use

4.1 This practice is intended to be used by the NDT using organization to measure the baseline performance of the DDA and to monitor its performance throughout its service as an NDT imaging system.

4.2 It is to be understood that the DDA has already been selected and purchased by the user from a manufacturer based on the inspection needs at hand. This practice is not intended to be used as an “acceptance test” of the DDA, but rather to establish a performance baseline that will enable periodic performance tracking while in-service.

4.3 Although many of the properties listed in this standard have similar metrics to those found in Practice E2597, data collection methods are not identical, and comparisons among values acquired with each standard should not be made.

4.4 This practice defines the tests to be performed and required intervals. Also defined are the methods of tabulating results that DDA users will complete following initial baselining of the DDA system. These tests will also be performed periodically at the stated required intervals to evaluate the DDA system to determine if the system remains within acceptable operational limits as established in this practice or defined between user and customer (CEO).

4.5 There are several factors that affect the quality of a DDA image including the spatial resolution, geometrical unsharpness, scatter, signal to noise ratio, contrast sensitivity (contrast/noise ratio), image lag, and burn in. There are several additional factors and settings (for example, integration time, detector parameters or imaging software), which affect these results. Additionally, calibration techniques may also have an impact on the quality of the image. This practice delineates tests for each of the properties listed herein and establishes standard techniques for assuring repeatability throughout the lifecycle testing of the DDA.

5. General Testing Procedures

5.1 The tests performed herein can be completed either by the use of the five-groove wedge phantom (see Fig. 1) or with separate IQIs on the Duplex Plate Phantom (see Fig. 2).

5.2 *DDA Calibration Method*—Prior to testing, the DDA shall be calibrated for offset and, or gain to generate corrected

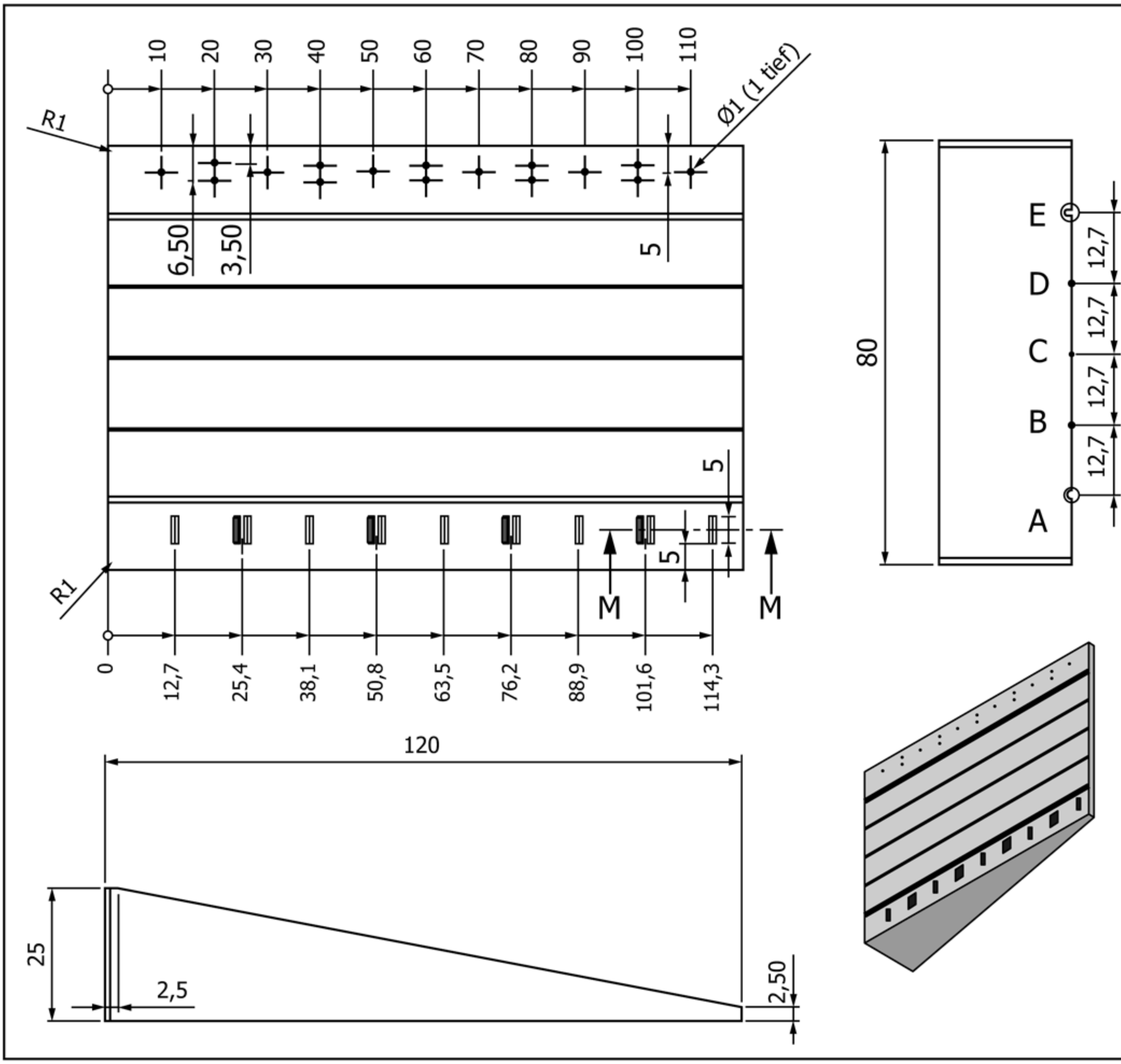


FIG. 1 5-Groove-Wedge (steel) – see Appendix

images per manufacturer's recommendation. It is important that the calibration procedure be completed as would be done in production during routine calibration procedures, and that these same procedures be used throughout the periodic testing of the DDA after it is in-service.

5.3 *Bad Pixel Standardization for DDAs*—Images collected for testing shall be corrected for bad pixels as would be done in production during routine bad pixel correction procedures per manufacturer's recommendation wherever required. A standardized nomenclature is presented in Practice E2597. The identification and correction of bad pixels in a delivered DDA remain in the purview of agreement between the user and the system manufacturer. The various tests shall be completed under similar conditions as in production. Some parameters to control are listed below. If several different energies are used in production, the complete settings with the highest energy level shall be used for these tests.

5.3.1 X-ray tube voltage [kV]

5.3.2 tube current [mA]

5.3.3 focus detector distance (FDD) [mm]

5.3.4 object detector distance (ODD) [mm]

5.3.5 total exposure time per image [ms]

5.3.6 detector corrections (calibration and bad pixel substitution)

5.3.7 detector settings

5.3.8 image acquisition software and image processing

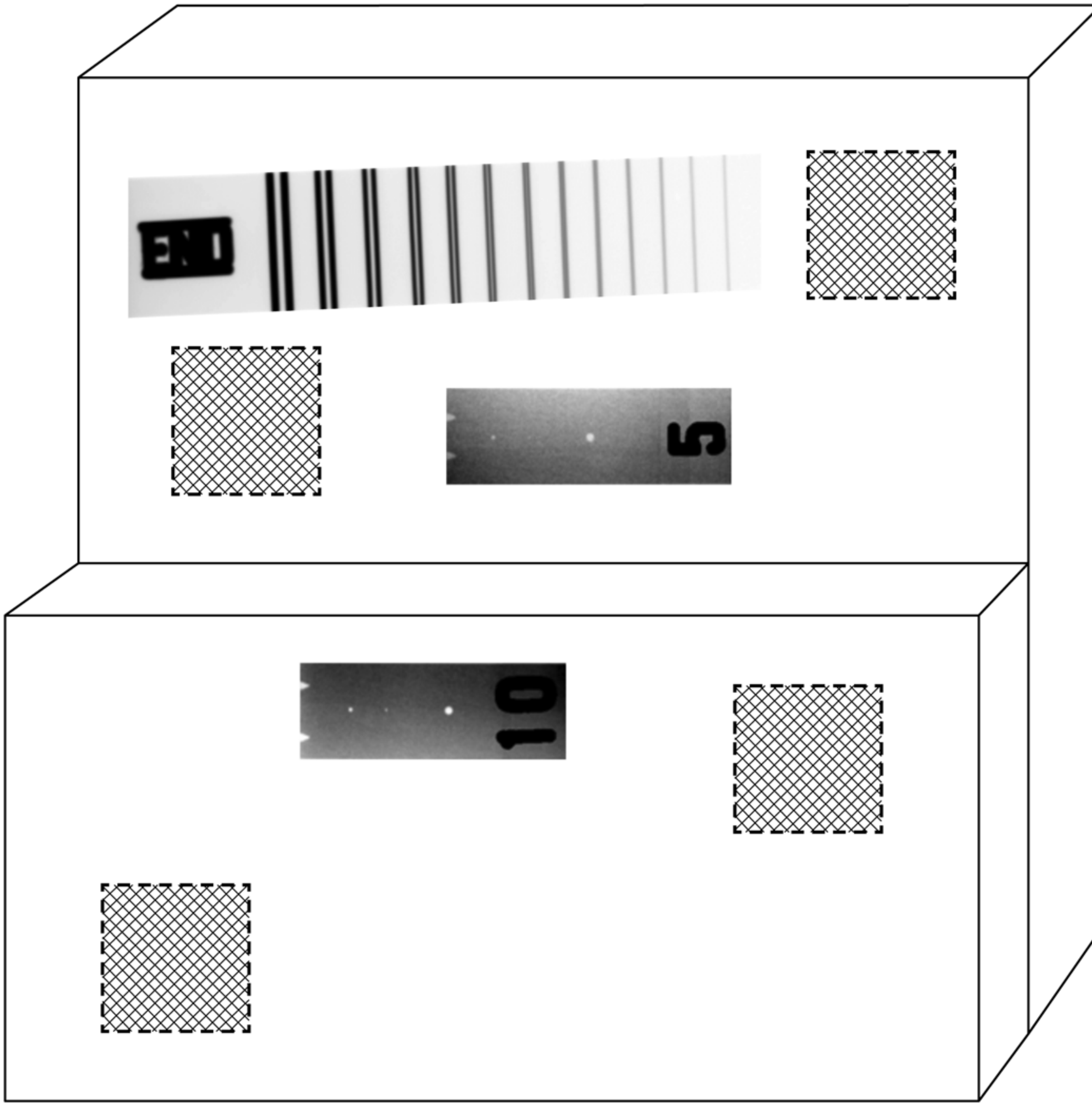


FIG. 2 Duplex Plate Phantom with IQIs positioned; one ASTM E1025 or E1742 Penetrameter on each plate and one ASTM E2002 Duplex Wire IQI on the thinner plate. The boxes *ROI 1 to ROI 4* are for evaluation of signal level and SNR.

6. Application of Baseline Tests and Test Methods

6.1 *DDA System Baseline Performance Tests*

6.1.1 The user shall accept the DDA system based on manufacturer's results of Practice E2597 on the specific detector as provided in a data sheet for that serialized DDA or other agreed to acceptance test between the user and manufacturer (not covered in this practice). The user baselines the DDA using the tests defined in Table 1. Additional tests are to be defined in agreement between the CEO and the using organization in terms of the specific tests to perform, how the data is presented, and the frequency of testing. This approach does the following:

6.1.1.1 Provides a quantitative baseline of performance,

6.1.1.2 provides results in a defined form that can be reviewed by the CEO and

6.1.1.3 offers a means to perform process checking of performance on a continuing basis.

TABLE 1 System Performance Tests and Process Check of the DDA System

System Performance Test			System Performance Test				Process Check			
Parameter		Unit	Base Line	Software Update	Tube Change	Detector Change/ Repair	Short Version	Long Version	Usage of Five-Hole Wedge	Duplex Plate Phantom
Spatial Resolution	SR	µm	x		x	x	x	x	x	x
Contrast Sensitivity	CS	%	x	x	x	x	x	x	x	x
Material Thickness Range	MTR	mm	x	x	x	x	x	x	x	x
Signal to Noise Ratio	SNR		x	x	x	x	x	x	x	x
Signal Level	SL		x	x		x	x	x	x	x
Image Lag	Lag	%	x			x		x		
Burn In	BI	%	x			x		x	x	x
Offset Level	OL		x	x	x	x		x		
Bad Pixel Distribution			x	x	x	x	x	x		

6.1.2 Acceptance values, and tolerances thereof obtained from these tests shall also be in agreement between the CEO and the using organization.

6.1.3 Acceptance levels for individual bad pixels, bad clusters, relevant bad clusters, and bad lines, and their statistical distribution within the DDA, as well as proximity to said anomalies is to be determined by agreement between the user and the CEO. The user and or CEO may refer to the Guide for DDAs (E2736), Practice E2597, as well as consult with the manufacturer on how the prevalence of these anomalous pixels might impact a specific application. This practice does not set limits, but does offer a means for tracking such anomalous pixels in the table templates provided herein.

6.1.4 Given that the other elements of the DDA system are within their tolerances including the x-ray source/generator, the imaging system, and the inspection itself (for example errors with gain/offset mapping are controlled, as is any severe x-ray scatter in the inspection), and the test produces a result below the "agreed to" requirements, the detector is not to be placed in service unless it is repaired, replaced, or some other change is instituted that will assure the quality of the inspection as stated in the agreement between contracting parties.

6.1.5 The results of the initial test of the new system shall be documented, as delineated in Table 2 and Table 3 and taken as reference values "Result (new)" for further use.

6.1.6 Maximum deviations from Result (new) as tolerances and limits defined between contracting parties shall also be documented in Table 2 and Table 3 as reference values "Limit" for further use.

6.1.7 If a replacement DDA is placed into service, the reference values from the acceptance test shall be updated, and a new baseline formed.

6.2 *User Tests After Repair, Hardware- or Software Upgrade*—After modifications, such as repair or upgrade of the DDA system hardware, specialized tests are required to prove the proper performance of the DDA system with the new conditions. With a new DDA the reference values from the acceptance test shall be updated, too. Changes of the functionality of the system (for example, by new software version), which influence the image quality, also need a test to prove the proper performance of the system after changes.

6.3 *User Tests for Long-Term Stability*—Quality assurance requires periodic tests of the DDA system to ensure the proper performance of the system. The time interval depends on the degree of usage of the system and shall be defined by the user with consideration of the DDA system manufacturer's information. There may be two versions of the long version stability tests, the complete program and a short version. The intervals for the performance checks shall not exceed ten days. The check for bad pixel shall be done daily. Details shall be agreed upon between the customer and the user.

7. Apparatus

7.1 The tests described in Table 1 and in Section 6 require the usage of either the five-groove wedge (see Fig. 1); or the Duplex Plate Phantom with separate IQIs—E2002 Duplex Wire and proper E1025 or E1742 penetrameters (see Fig. 2). However, this document does not preclude the use of other gauges or phantoms which can measure the same parameters listed in Table 1. The use of alternate gauges must be approved by the CEO.

7.1.1 The five-groove wedge shall be made from light metal as aluminum or heavy metal as stainless steel—selected based on the metal used in the application. Material and size can be taken from Appendix X1.

7.1.2 *Duplex Plate Phantom*—Two flat plates of the same material are used – either constructed from Aluminum (Material Group 02), Titanium (Material Group 01) or Stainless Steel (Material Group 1) – as needed to match the metal used in the application. The second plate covers half of the first plate (see Fig. 2). The thickness of the first plate is similar to the thinnest material thickness of the object in inspection, the thickness of both plate together is similar to the highest material thickness.

7.1.2.1 *Application Procedures for DDA system Quality Indicators*—The DDA system quality indicators provide an evaluation of the quality of a DDA system as well as for periodic quality control. Arrangement of the DDA system quality indicators shall be in accordance with this practice, or as specified by the CEO.

7.1.2.2 The E2002 Duplex Wire Gauge is placed on the thinner area as shown in Fig. 2. Two E1025 or E1742 penetrameters are placed on the plates, one on each plate of either the E1025 or the E1742, but not mixed, each adequate to the required contrast sensitivity (1-1T up to 4-4T). The four marked areas (*ROI 1 to ROI 4*) shall be left uncovered (see Fig. 2).

TABLE 2 Test Report of DDA SystemReport of Bad Pixels and Clusters

DDA System			kV	energy
Construction Year			mA	tube current
Last Service				pre filter (material and thickness)
Detector Settings			mm	focus detector distance
Software			mm	object detector distance
Software Version			s	total exposure time per image

Used IQI	☐	5 Hole Wedge	☐	Duplex Plate Phantom (separate IQIs)

Test:	☐	Acceptance Test
	☐	Test after Repair or new Software
	☐	Longterm Stability (short version)
	☐	Longterm Stability (long version)

Tests	Unit	Result (new)		Limit		Result		Remark
		thin	thick	thin	thick	thin	thick	
Spatial Resolution SR	µm							
Contrast Sensitivity* CS	%							
Material Thickness Range MTR	mm							
Signal to Noise Ratio SNR								
Signal Level SL								
Image Lag 1f Lag	%							
Burn In 1 / 10 min BI	%							
Offset Level OL								
Bad Pixel Distribution		OK						

Date of Tests	
Conclusion	
Operator	

* Two columns only needed when using Duplex Plate Phantom

8. Test Procedures

8.1 The tests listed in this section shall be performed with the listed phantom and corresponding IQIs at specified intervals as established in this practice and/or between the user of the DDA and the CEO. The radiation parameters of the performed tests, the date and operator name shall be included in all documentation.

8.1.1 *Core Image Quality Tests:*

8.1.1.1 Spatial resolution (by five-groove wedge or duplex plate phantom and duplex-wire method),

8.1.1.2 Contrast sensitivity (by five-groove wedge or duplex plate phantom with separate IQIs),

8.1.1.3 Signal to Noise Ratio (by five-groove wedge or duplex plate phantom with separate IQIs),

8.1.1.4 Signal level (by five-groove wedge or duplex plate phantom with separate IQIs),

8.1.1.5 Bad Pixel distribution (any relevant cluster shall be noted and Bad Pixel Map stored).

8.1.2 In applications with a larger material thickness range, for example for castings, the maximum material thickness range within one image for inspection shall be measured and included in the list above (see 8.1.1).

8.1.2.1 Material Thickness Range (by five-groove wedge or duplex plate phantom).

8.1.3 Image Lag and Burn In shall be measured at user/CEO defined intervals to test the temporal behavior of the DDA system for residual images following an exposure.

8.1.3.1 Image lag (no test object required).

8.1.3.2 Burn-in (by the five-groove wedge or the duplex plate phantom)

8.1.4 Degradation of the DDA may reduce the system sensitivity after extensive usage. For this reason, the DDA system shall be checked for increasing offset value at user-defined intervals.

8.1.4.1 Offset value (DDA response with no DDA corrections and without radiation).

8.2 *Procedure*—For the tests involving the phantoms of this practice, either the five-groove wedge or the duplex plate phantom shall be placed in the beam at the position which is designed for the test object with same focal spot detector distance (FDD) and object detector distance (ODD). X-ray settings (kV, mA, and focal spot) shall be the same as in the application.

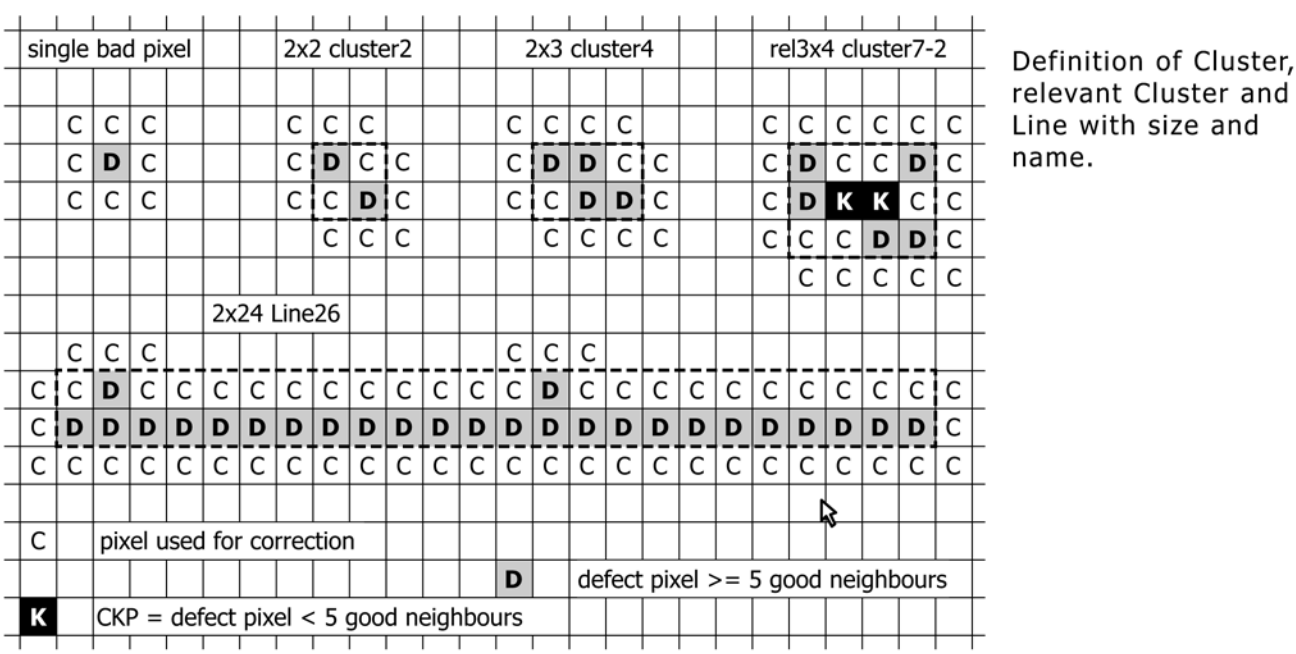
TABLE 3 Report of Bad Pixels and Clusters

Bad Pixel Definition Thresholds:			
Underperforming Low Threshold	=		%
Underperforming High Threshold	=		%

Name of the Bad Pixel Image: ______________________

Bad Pixel Summary:		Result (new)	Limit	Result	Okay/Not Okay	Remark
No Total Bad Pixels	=					
No of relevant Cluster	=					
No of remaining irrelevant Cluster	=					
No of Bad Lines	=					
Size / Name of relevant Cluster #1				No of ClusterKernelPixel =		
Position of relevant Cluster #1		X1	X2	Y1	Y2	
Size / Name of relevant Cluster #2				No of ClusterKernelPixel =		
Position of relevant Cluster #2		X1	X2	Y1	Y2	
Size / Name of relevant Cluster #3				No of ClusterKernelPixel =		
Position of relevant Cluster #3		X1	X2	Y1	Y2	

Date of Tests	
Conclusion	
Operator	



8.2.1 Note that for tracking performance of a DDA, the same technique shall be used during long term stability or process checking, even if there is a change in the conditions or technique of the application at hand.

8.2.2 Before the capture of images for the evaluation begins, the DDA shall be calibrated in accordance with the manufacturer's recommendation. This includes offset, gain and bad pixel calibrations. The system shall calculate for Bad Pixels in accordance with manufacturer's procedures (for example, see Practice E2597) and shall present them in a Bad Pixel Image and/or a list for analysis by the user.

8.2.3 Exposure of DDA system quality indicators (user test) with the five-groove wedge:

8.2.3.1 The side with the grooves of the five-groove wedge shall face toward the radiation source, and its projection shall fit within the grid of the detector.

8.2.3.2 An image shall be acquired with identical DDA and tube settings as those used in service, including the same exposure time under similar conditions as in production.

8.2.4 Exposure of DDA system quality indicators (user test) with duplex plate phantom with the separate IQIs:

8.2.4.1 The side with the IQIs shall face the radiation source.

8.2.4.2 An image shall be acquired with identical DDA and tube settings as those used in service, including the same exposure time under similar conditions as in production.

8.2.5 *Procedure for Lag Measurement*—For this measurement no offset- or gain-correction shall be applied.

8.2.5.1 The lag of the detector shall be measured using a sequence of images. The DDA shall be powered ON and not exposed for more than 30 minutes. Before starting, an offset frame (*L Img 0*) shall be captured (without radiation).

8.2.5.2 The DDA shall be exposed with a constant dose rate with the selected energy at about 80 % of saturation gray value of the DDA for a minimum of 60 seconds.[3] If the 80 % level can not be achieved, maximum power of the tube at the selected energy shall be used. An image (*L Img 1*) shall be captured with about 10 s total integration time during the 60 seconds X-ray on time, (for example, using 1-second frame times, and averaging all 10 frames).[4]

8.2.5.3 With the X-rays remaining on, a sequence of images shall then be captured for about 20s while shutting down the X-rays after approximately three seconds.

8.2.6 *Procedure for Burn-In Measurement*—For this measurement offset and gain-correction shall be applied.

8.2.6.1 Burn-in shall be measured at same energy as the other tests. The thick area of the 5-groove-wedge or of the Duplex Plate Phantom shall be placed directly on the surface of the DDA in a way that the edge of the phantom is in the center of the DDA.

8.2.6.2 The DDA shall be exposed for ten minutes with 80 % of saturation gray value of the DDA in the area not covered by the phantom—adjusted with the tube current. If the 80 % level cannot be archived, maximum power of the tube at the selected energy shall be used.

8.2.6.3 The X-rays shall be switched off and the phantom shall be removed from the beam.

8.2.6.4 The DDA shall be exposed at the same energy but at a tenth of the original exposure dose. An image with ~10 s total exposure time shall be captured (*BI Img 1*)[4]. A shadow in the area where the phantom was previously located may be slightly visible.

8.2.6.5 The measurement shall be repeated after ten minutes without further exposure between measurements (*BI Img 10*).

8.2.7 *Procedure for Measurement of the Offset Level:*

8.2.7.1 Before measurement of the Offset Level the DDA should be powered-on 30 minutes to get the DDA stabilized at temperature. The DDA shall not be exposed for ten minutes. One image with about 30-s integration time shall be captured without radiation (*OF Img*). Bad Pixel Correction is active, no gain or offset correction shall be done.

8.2.8 *Procedure for Evaluation of Bad Pixel:*

8.2.8.1 The evaluation for bad pixel shall be done as recommended by the manufacturer or system supplier. An image shall be stored where the bad pixels are marked (*BP Img*). Optionally, a list of the bad pixels in a text file may be stored.

9. Calculation of the Results and Report

9.1 All test results shall be documented using the data sheet format as shown in Table 2.

9.2 The bad pixel image (*BP Img*) shall be evaluated for pixels out of specification, clusters, relevant clusters and lines, and statistical distribution within the DDA, including proximity among the anomalous pixels. These shall be documented by using the data sheet format as shown in Table 3. If an out of specification (as agreed between CEO and user) condition occurs, the DDA is to be repaired or replaced or an action has to be taken as agreed between user and CEO.

9.3 The results using the five-groove wedge and the Image *PI Img 5HW* shall be calculated as follows:

9.3.1 *Spatial Resolution*—The smallest long groove which is visible in the image at the smallest material thickness shall be determined and noted as SR_{min}.

9.3.1.1 Determine the required geometrical resolution, and select the groove from the five present that best fits this required resolution.

9.3.1.2 Draw a line profile with 11-pixel width perpendicular to the groove, beginning at the smallest thickness of the wedge. Move the line profile to the thicker material area. Move the line until the selected groove disappears in the noise. Note the material thickness (MT). See Fig. 3 for an example procedure.

9.3.2 *Contrast Sensitivity*—Contrast sensitivity (CS) is calculated by dividing the diameter of the selected groove by the noted material thickness.

$$CS\,[\%] = groove\ diameter/MT \tag{1}$$

9.3.3 *Material Thickness Range*—The resolved material thickness range MTR_{res} is MT.

9.3.4 *Signal to Noise Ratio*—A ROI is drawn beside the selected groove at the material thickness where the groove disappears in the noise (for position and size of the ROI refer to Fig. 4). Measure the mean gray value and the median single line standard deviation (noise). SNR is the quotient of both.

$$SNR = mean\ grey\ value/median\ single\ line\ standard\ deviation \tag{2}$$

[3] The saturation gray value is provided by the manufacturer.

[4] DDAs can operate in either an extended exposure mode where a single frame may be acquired for 10 s, or multiple frames can be acquired and averaged over the same 10 s. The user is to select the appropriate frame time for the DDA at hand based on manufacturer's recommendations and typical exposure times used for production.

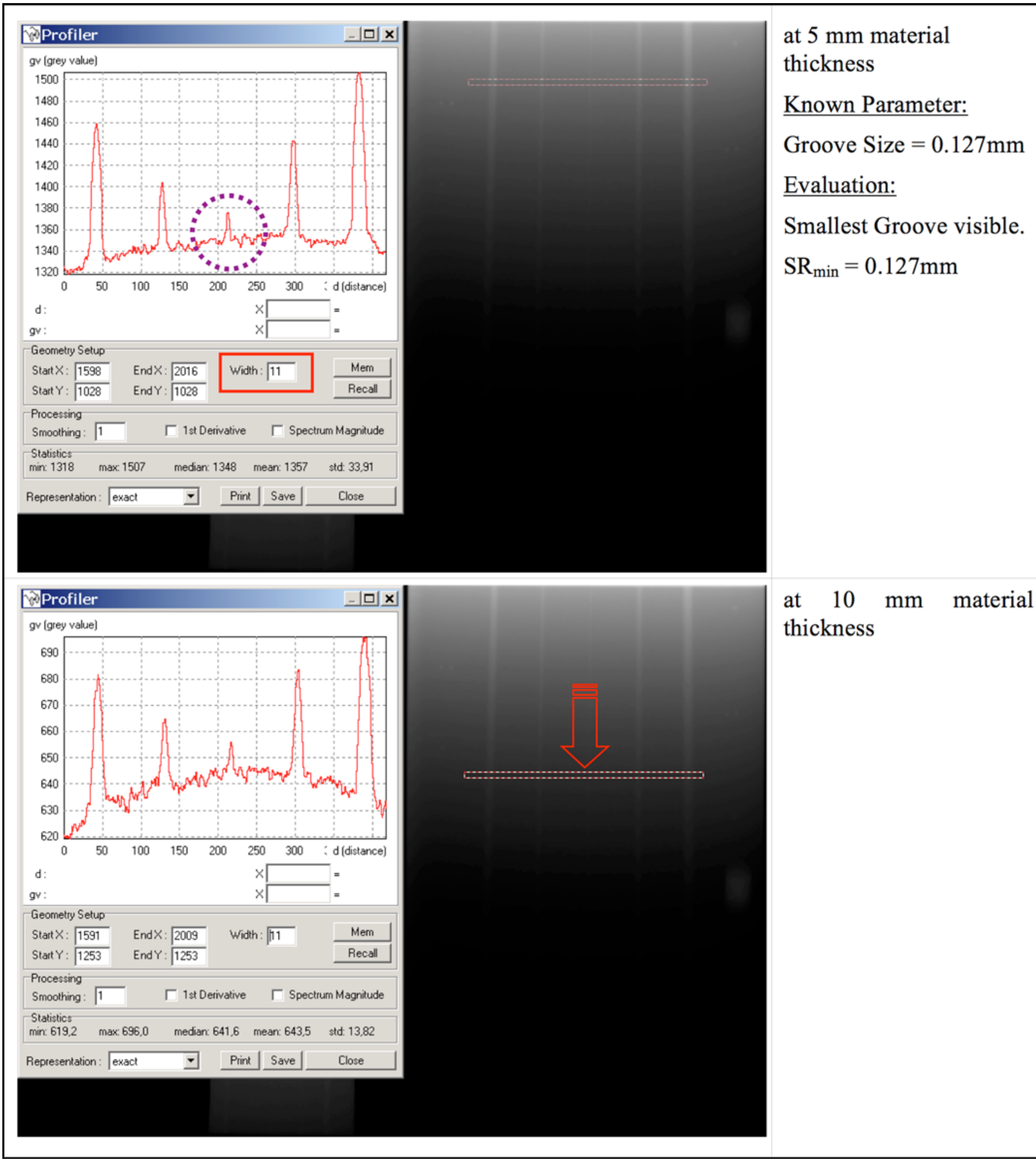


FIG. 3 Moving the Line Profile on the Wedge from Thin to Thicker Material

9.3.5 *Signal Level*—The ROI is moved to the thinnest area of the five-groove wedge to note the median single line gray value (GV_{thin}). Additionally note the median single line grey value from 9.3.4 (GV_{thick}) (for position and size of the ROI refer to Fig. 5).

9.4 The results using the Duplex Plate Phantom with separate IQIs and the Image *PI Img DPP* shall be calculated as follows:

9.4.1 *Spatial Resolution*—A line profile is created through the duplex wire gage such that the profile covers approximately

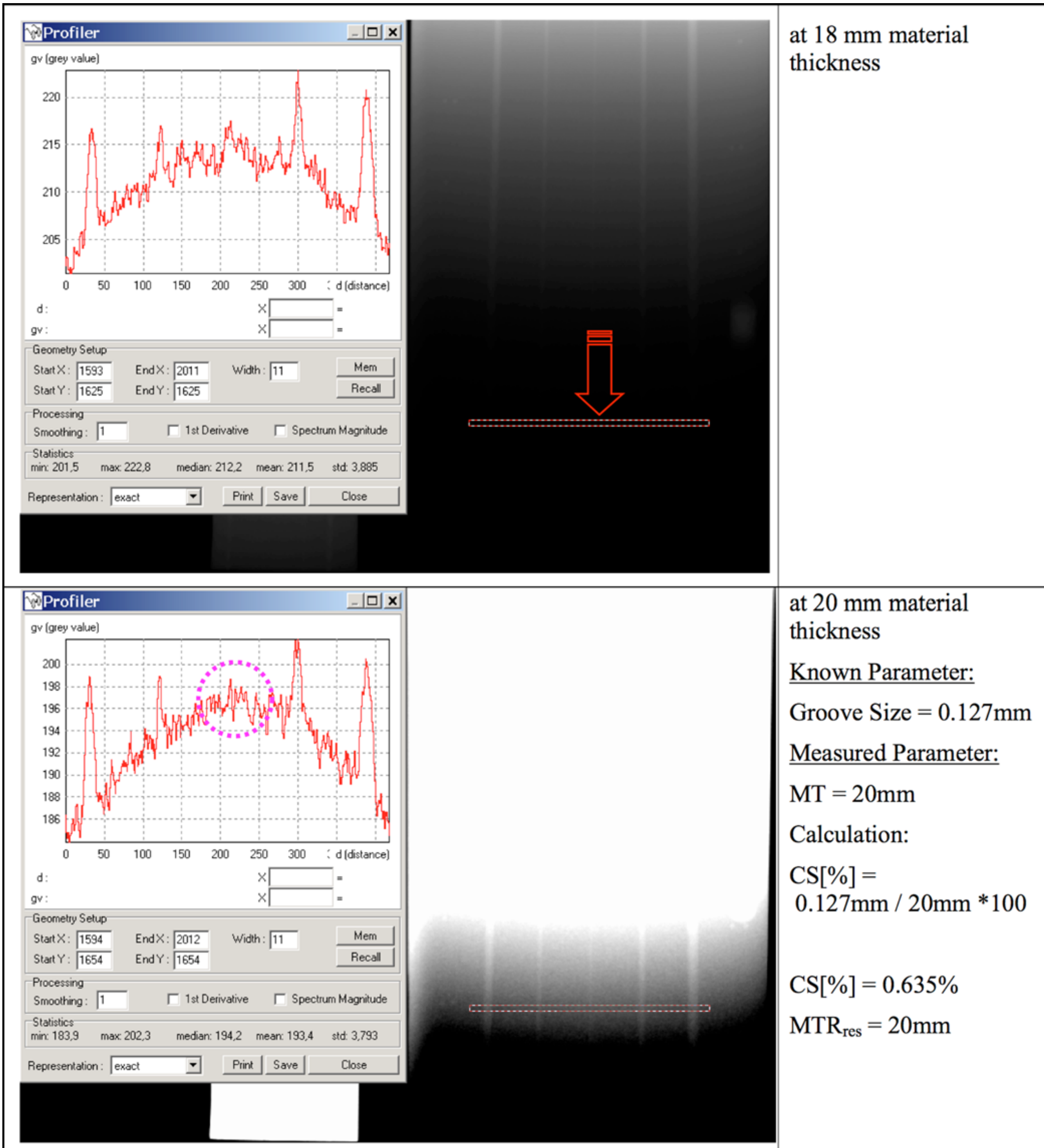


FIG. 3 At 20 mm the middle line can not be seen any more *(continued)*

60 % of the width of the duplex wires (see Fig. 6). Determine the largest wire pair with less than 20 % dip resolution and note the wire distance as SR_{min}.

9.4.2 *Contrast Sensitivity*—Contrast sensitivity (CS) is calculated by the difference in Signal due to the 1T hole (or 2T hole) divided by the noise around the hole (see Fig. 7) in relation to the quotient of the material thickness of the step and the penetrameter. The diameter of the hole [in pixels] shall be measured as D_{hole}. A small ROI with half of the size of the diameter D_{hole} shall be placed inside the hole. The median grey value of the ROI shall be taken as GV_{median}[hole]. Two square boxes with double the size of D_{hole} and four times the size of D_{hole} shall be drawn about the hole as shown in Fig. 7. The mean grey value of the area between both boxes shall be

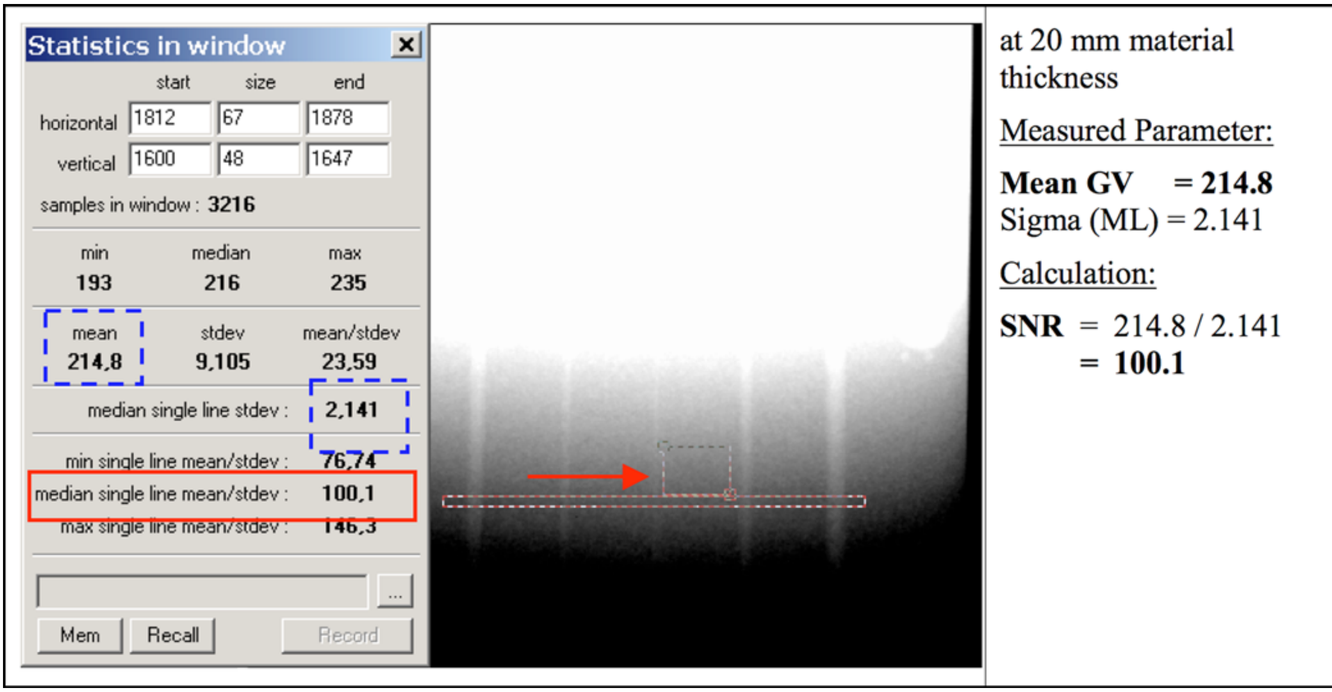


FIG. 4 Measure the Mean Grey Value (Signal Level) and Median Single Line Standard Deviation (Sigma)

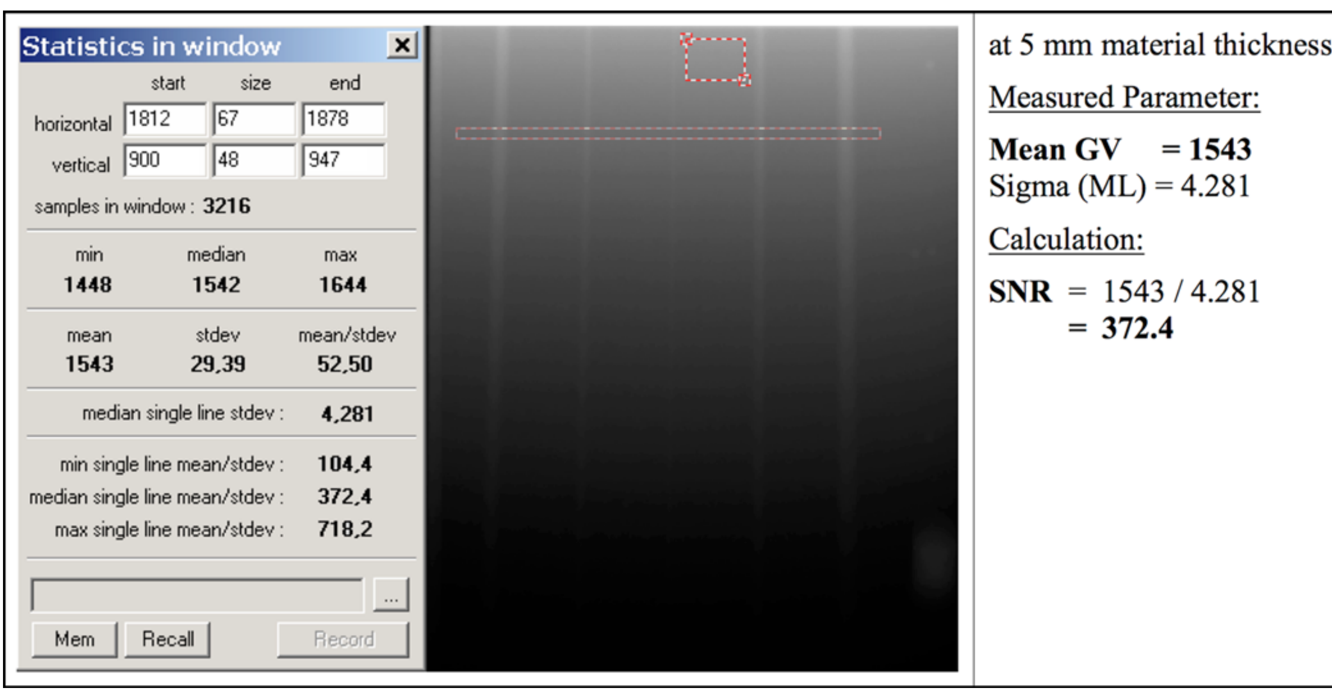


FIG. 5 Measurement of Signal Level with Five-Groove Wedge in Thin Area (Thick Area: see Fig. 4).

measured as GV_{mean}[beside squares]. The standard deviation in that area between the boxes shall be measured as Sigma[beside squares]. The Contrast to Noise Ratio CNR shall be calculated to:

$$CNR = GV_{median}[hole] - GV_{mean}[beside\ squares]/Sigma[beside\ squares] \quad (3)$$

With the total material thickness at the position of the IQI (base material + IQI thickness) MT_{total} and the thickness of the IQI MT_{IQI} the Contrast Sensitivity is:

$$CS[\%] = \frac{GBV}{CNR} * \frac{MT_{IQI}}{MT_{total}} * 100 \quad (4)$$

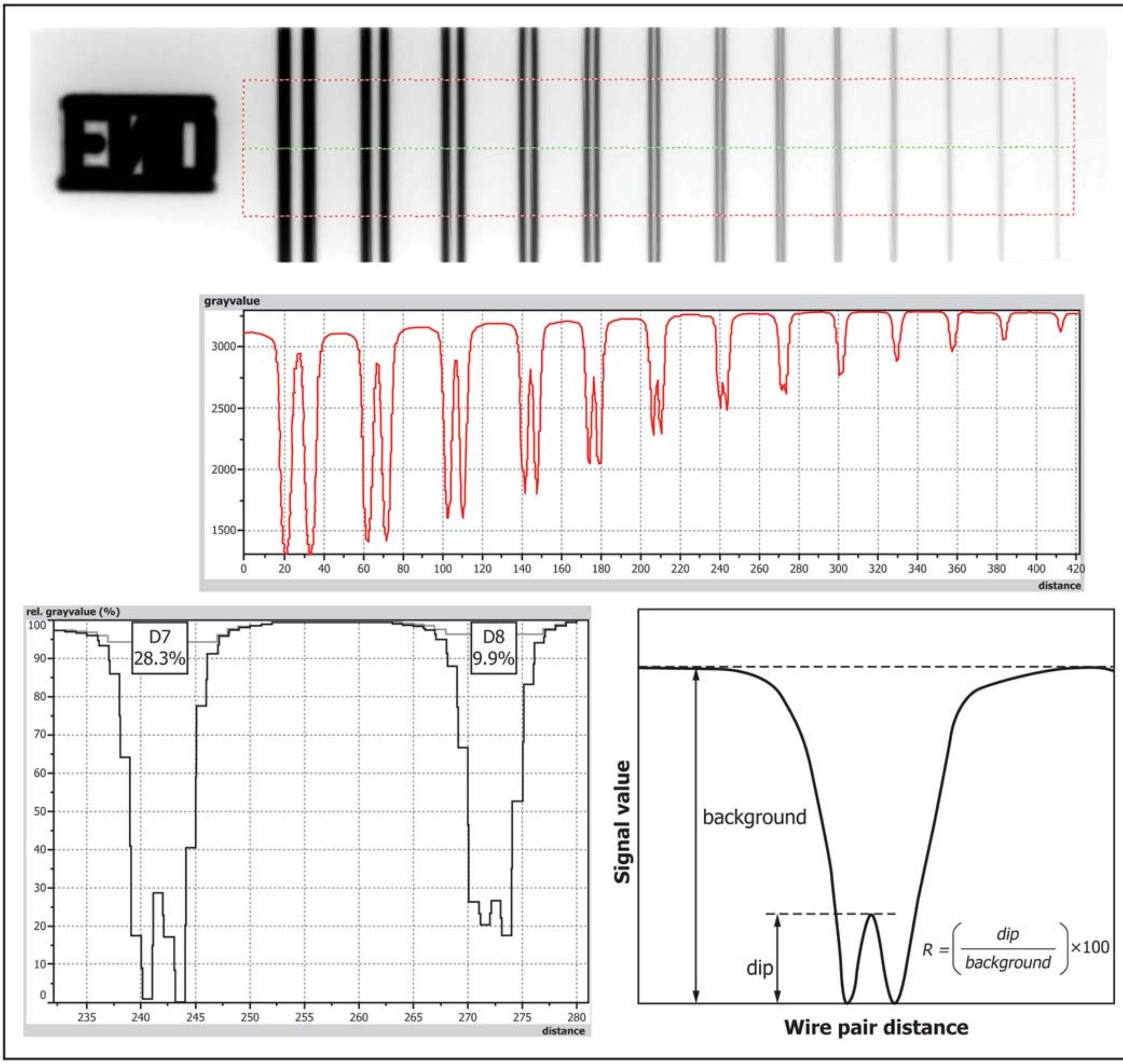


FIG. 6 Wire-Pair Image Analysis for Calculation of Spatial Resolution. D8 < 20 %: 160 μm Resolution.

where GBV is the required contrast of the hole. For aerospace applications GBV should be 2.5. This value shall be agreed between user and customer. The values for the thin and the thick region of the Duplex Plate Phantom shall be documented.

9.4.3 *Material Thickness Range*—No maximum material thickness range can be evaluated with this tool. The largest material thickness is covered by the thick area of the Duplex Plate. If CNR>GBV this material thickness can be inspected and the test is passed.

9.4.4 *Signal to Noise Ratio*—For measurement of SNR two ROIs of a minimum of 50 by 50 pixels on the thin (ROI 1 and ROI 2) and two on the thick area (ROI 3 and ROI 4) shall be drawn at the locations of the Duplex Plate Phantom as shown in Fig. 2. The absolute mean signal GV_{mean} and the standard deviation (Sigma) of each ROI shall be measured. SNR is the quotient of both.

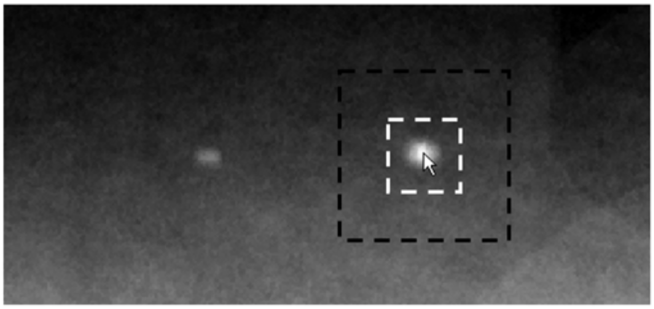
$$SNR_{thick} = \left(\frac{GV_{mean}(ROI\ 3)}{Sigma(ROI\ 3)} + \frac{GV_{mean}(ROI\ 4)}{Sigma(ROI\ 4)}\right)*0.5 \quad (5)$$

$$SNR_{thin} = \left(\frac{GV_{mean}(ROI\ 1)}{Sigma(ROI\ 1)} + \frac{GV_{mean}(ROI\ 2)}{Sigma(ROI\ 2)}\right)*0.5$$

9.4.5 *Signal Level*—The signal level for the thin and the thick material can be taken from 9.4.4:

$$GV_{thin} = [GV_{mean}(ROI\ 1) + GV_{mean}(ROI\ 2)]*0.5 \quad (6)$$

$$GV_{thick} = [GV_{mean}(ROI\ 3) + GV_{mean}(ROI\ 4)]*0.5$$



$$CNR = \frac{GV_{median}[hole] - GV_{mean}[beside\ squares]}{Sigma[beside\ squares]}$$

$$CS\,[\%] = \frac{GBV}{CNR} * \frac{MT_{IQI}}{MT_{total}} * 100$$

Known Parameter:

MT_{step} = 50 mm; MT_{IQI} = 0.5 mm

GBV = 2.5

Measured Parameter:

GV_{median} [hole] = 4800

GV_{mean} [beside squares] = 4600

Sigma [beside squares] = 50

Calculation:

MT_{total} = 50.5 mm

CNR = 4800 – 4600 / 50 = 4

CS [%] = 2.5 / 4 * 0.5 mm/50.5 mm * 100

CS [%] = 0.6188%

FIG. 7 Calculation and Example of Contrast Sensitivity Using the Hole Penetrameter

9.5 *Calculation of the Results from the Other Images:*

9.5.1 Image lag shall be calculated from the sequence of images taken in 8.2.5.

9.5.1.1 The sequence shall be evaluated and the image where a part is still bright and the other part is already dark shall be selected [*L Img S0*]. A ROI of about 50 by 10 pixels shall be drawn in the area where the signal level is about 85 % of the signal level in image *L Img 1* for the same ROI. The mean gray value of the ROI of *L Img 1* shall be noted as GV_{mean} (L1) (see Fig. 8).

9.5.1.2 The next image in the sequence [*L Img S1*] shall be taken and the same ROI shall be drawn at the same position in that image. The mean grey value in the ROI of image *L Img S1* shall be noted as GV_{mean}(LS1).

9.5.1.3 The same ROI shall be drawn at the same position in the offset image *L Img 0*. The mean grey value in the ROI of image *L Img 0* shall be noted as GV_{mean}(L0).

9.5.1.4 Image lag shall be calculated as the quotient of both gray values corrected by the offset value.

$$Lag\,[\%] = [GV_{mean}(LS1) - GV_{mean}(L0)]/[GV_{mean}(L1) - GV_{mean}(L0)]*100 \quad (7)$$

9.5.2 Burn-in shall be calculated from images taken in 8.2.6. Draw an ROI on the edge of the wedge and another beside the wedge with only a few pixel distance in the image of *BI Img 1* (see Fig. 9). Calculate the mean grey value of both ROIs and calculate Burn In. Redo the same with the image after ten minutes *BI Img 10*.

$$Burn - In(BI\ Img\ 1) = |(GV1 - GV2)|/GV2*100\,[\%] \quad (8)$$

$$Burn - In(BI\ Img\ 10) = |(GV1 - GV2)|/GV2*100\,[\%]$$

9.5.3 *Offset Level*—In the image without radiation *OF Img* a ROI of about 90 % of the active area of the DDA shall be drawn. The mean signal level in the ROI shall be noted as GV_{mean} (Offset).

10. Display of the Results

10.1 The user shall document all tests, its conditions and results. The period of testing shall meet the requirements in 6.3. It shall be documented in the company's written procedure and agreed between the contracting parties.

10.2 The results of the evaluations shall be summarized in Table 2.

10.3 The results of the bad pixel test shall be summarized in Table 3. An image where the bad pixels are marked shall be additionally stored.

11. Actions After Mismatch of the Limits in the Test Results

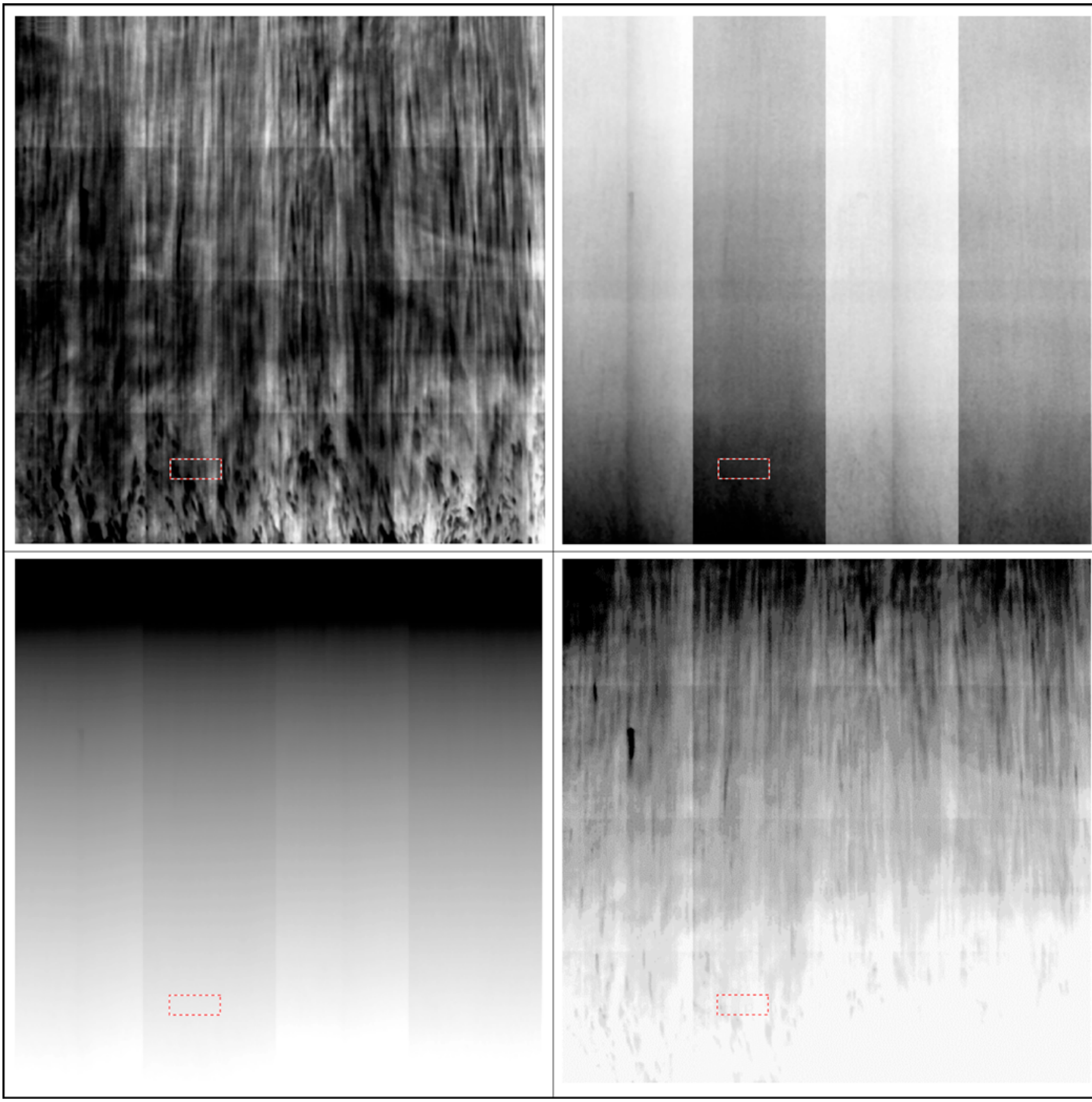
11.1 If an out of specification (as agreed between CEO and user) result of a test occurs, an action has to be taken to bring the system into the limits again (for example, the DDA is to be repaired or replaced) or an agreement with the CEO has to be achieved about this deviation to the specification.

12. Precision and Bias

12.1 No statement is made about the precision or bias of this practice. The results merely state whether there is conformance to the criteria for success specified in the procedure.

13. Keywords

13.1 bad pixels; contrast sensitivity; DDA; five-groove wedge; image lag; material thickness range; SNR; spatial resolution



1. Row: Image without radiation (L Img 0 - left) and Image with 80% Grey Level (L Img 1 - right).
2. Row: Image during shut down of X-ray (L Img S0 - left) and the image after (L Img S1 - right)
Example:
GVmean(L0) = 3510; GVmean(L1) = 46336;
GVmean(LS0) = 39371 [~85% of GVmean(L1)]; GVmean(LS1) = 5233;
Lag [%] = [(5233 – 3510) / (46336 – 3510)] * 100 = 4,02%

FIG. 8 Measurement of Image Lag from the Sequence

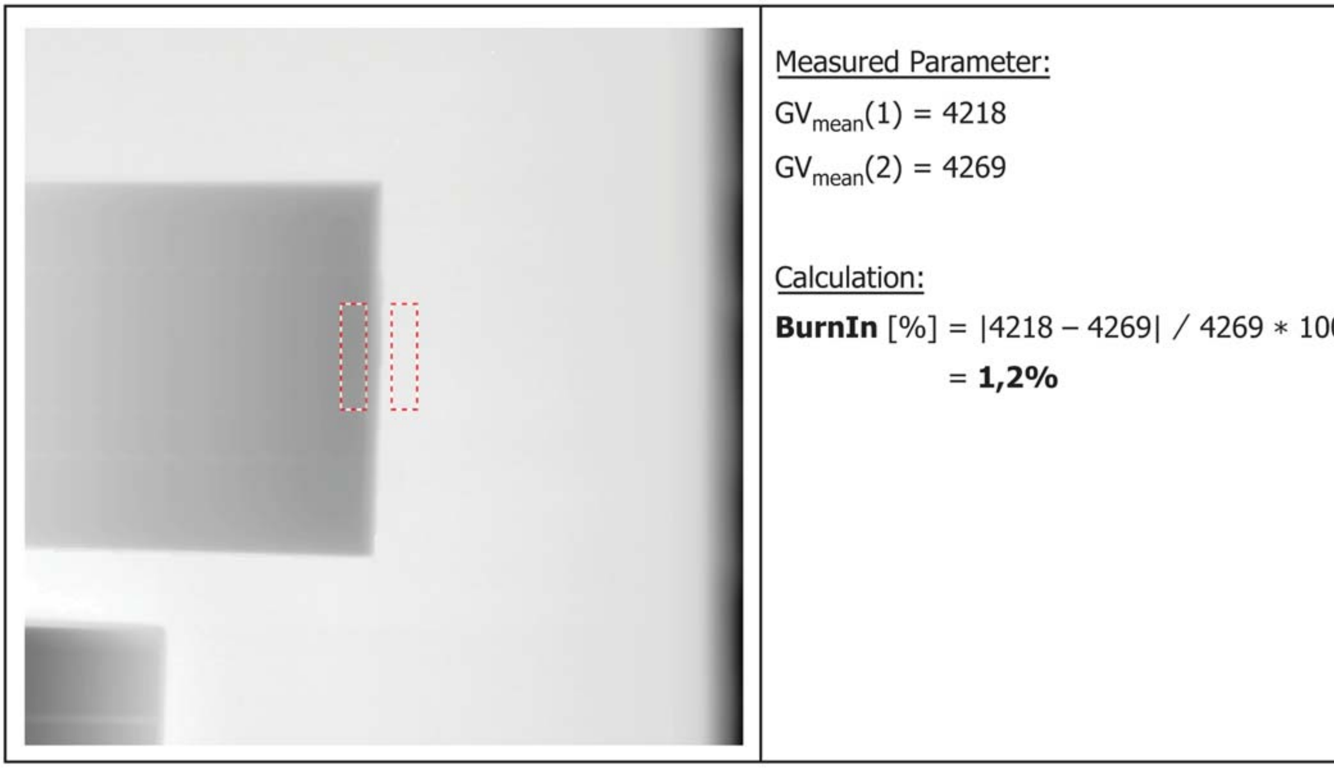


FIG. 9 Measurement of Burn In with the Edge of the Five-Groove Wedge

APPENDIX

(Nonmandatory Information)

X1. ASSEMBLING THE FIVE-GROOVE WEDGE

X1.1 While manufacturing the five-groove wedge it has to be assured that the material of the grooves is completely removed from the wedge. It should be avoided to create the grooves by pressing the material into the wedge around the grooves.

X1.1.1 Suggested method for manufacturing the five-groove wedge is to mill out the material with a precision milling machine using a special milling cutter (cherry). Fig. X1.1 shows the design of the cutter.

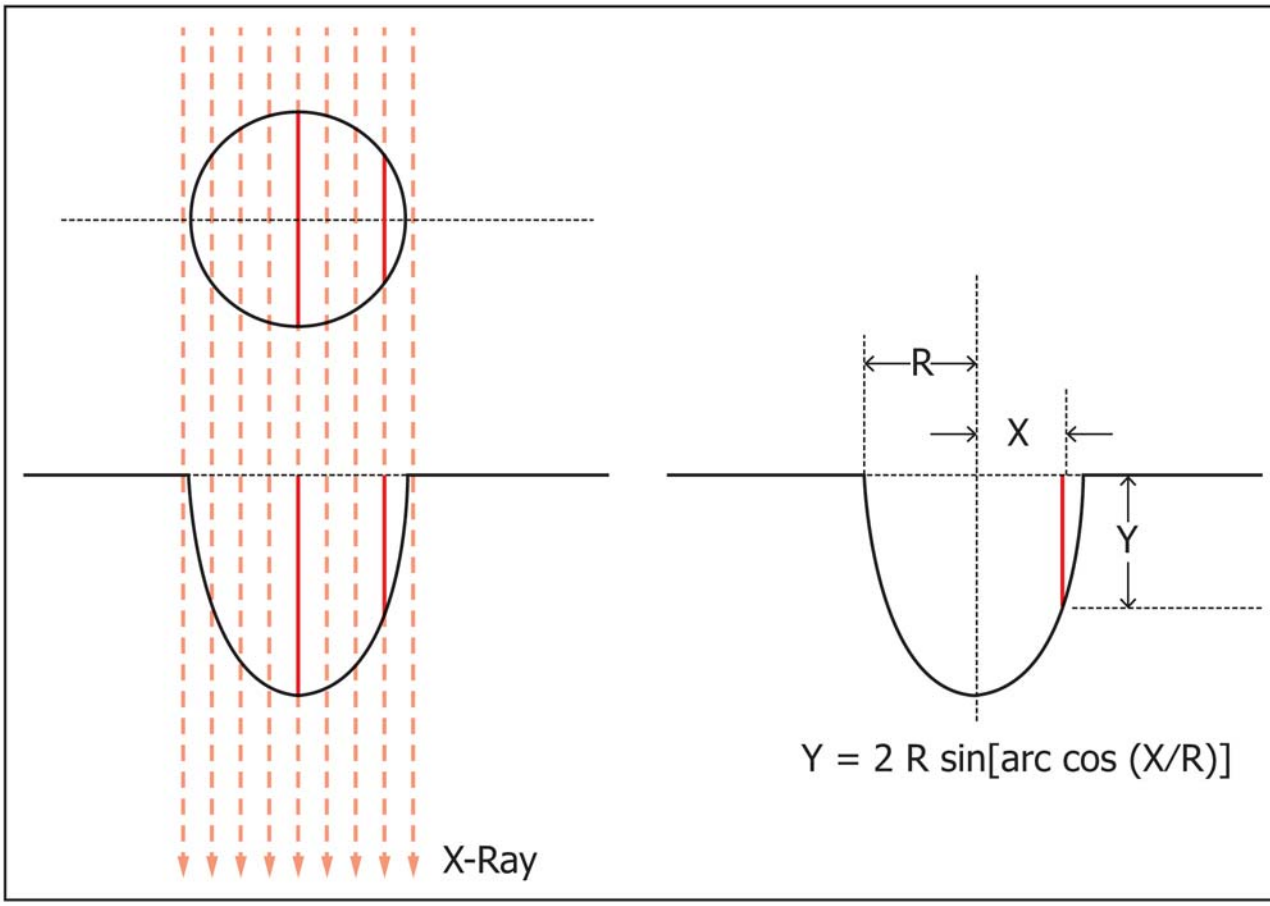


FIG. X1.1 Design of the Milling Cutter for the Five Grooves

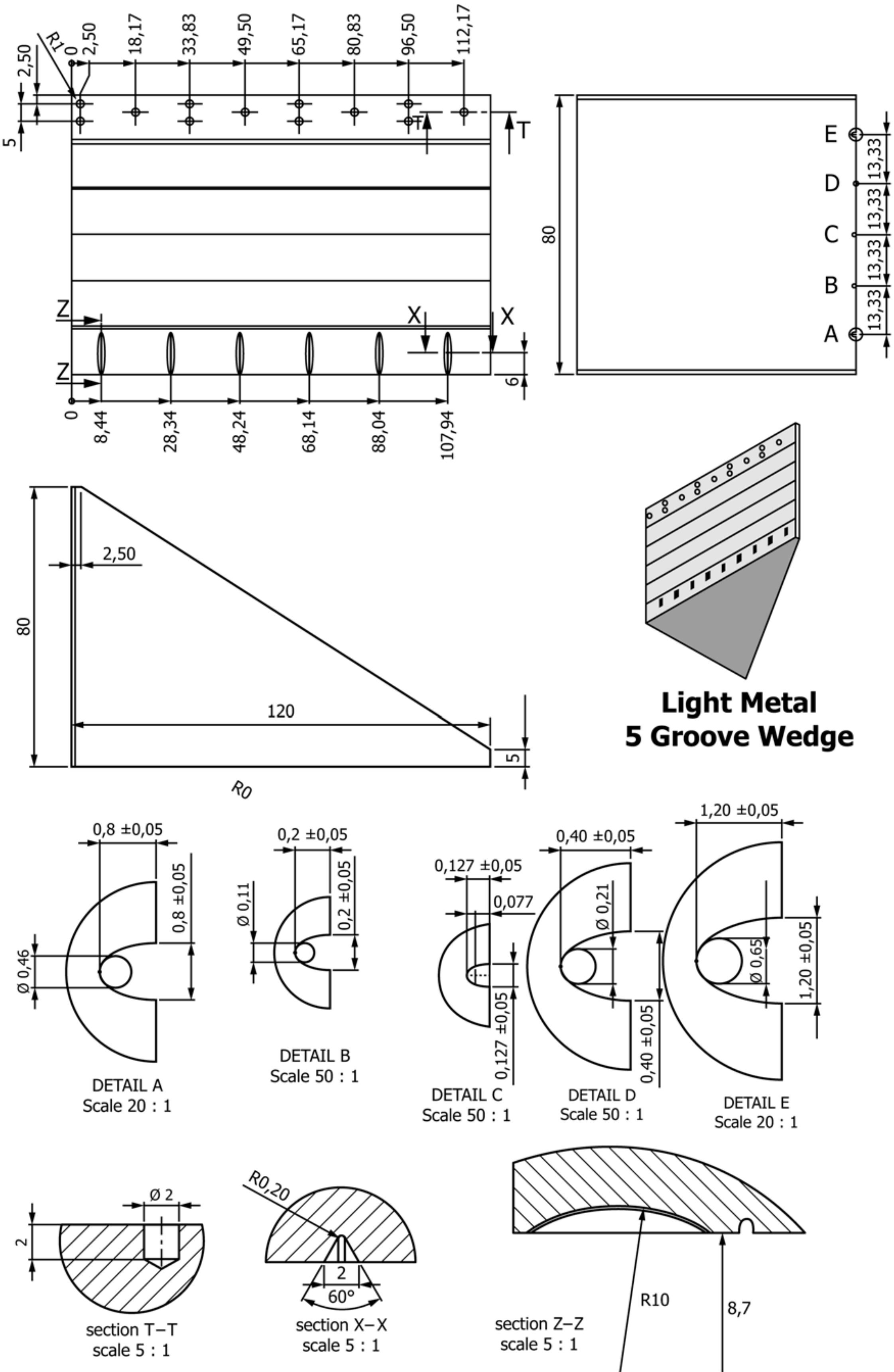


FIG. X1.2 Drawing of F-Groove Wedge for Light Metals

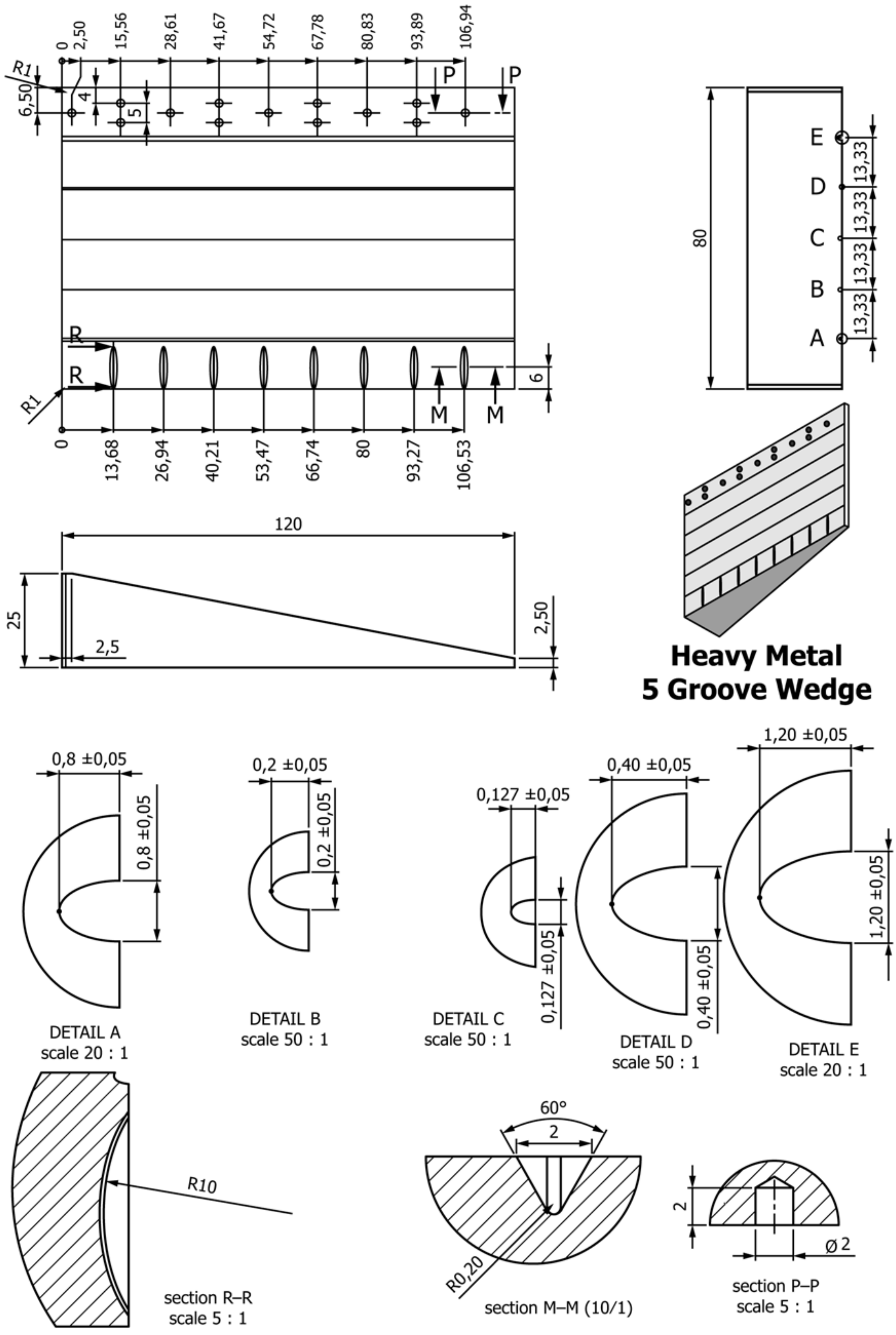


FIG. X1.3 Drawing of F-Groove Wedge for Heavy Metals