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Non-destructive testing of welds - Radiographic testing - Part 2: X-and gamma-ray techniques with digital detectors

焊缝无损检测 射线检测 第 2 部分：使用数字化探测器的 X 和伽马射线技术

(ISO 17636-2:2013, MOD)

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Non-destructive testing of welds - Radiographic testing - Part 2: X-and gamma-ray techniques with digital detectors

1 Scope

This part of GB/T 3323 is based on the basic theory and practical experience of digital radiography; specifies the general technology and requirements using computer radiography (CR) technology and digital imaging (DR) technology, which use the digital detector array (DDA), to perform X-and gamma-ray digital detection, for the welded joints of metal materials, including the technical level, general requirements, recommended technologies of X-and gamma-ray digital detection technology (detector system's selection, penetration technology control, image acquisition and display requirements), etc.; specifies the minimum requirements for obtaining digital detection images, which have the equivalent detection sensitivity as the film-based radiographic detection technology, in Part 1 of this standard (GB/T 3323.1).

This part applies to using the CR technology, which uses storage phosphor imaging plate (IP plate), and DR technology, which uses digital detector array (DDA), to detect the welded joints of plate and pipe OR other welded joints.

This part does not include the acceptance level of digital radiographic testing of welded joints of metallic materials.

If the parties to the contract use testing conditions, which are lower than this part, the quality of the testing images is very likely to drop significantly.

2 Normative references

The following documents are essential to the application of this document. For the dated documents, only the versions with the dates indicated are applicable to this document; for the undated documents, only the latest version (including all the amendments) is applicable to this standard.

GB/T 9445 Non-destructive testing - Qualification and certification of NDT personnel (GB/T 9445-2015, ISO 9712:2012, IDT)

GB/T 12604.2 Non-destructive testing - Terminology - Terms used in radiographic testing (GB/T 12604.2-2005, ISO 5576:1997, IDT)

The choice of digital radiography technology shall be agreed upon, by all parties to the contract.

The Level A and Level B technologies of digital radiography shall have the same recognizability of the equivalent defects, as the level A and level B technologies of radiography. The recognizability shall be verified by the image quality indicator, which is specified in GB/T 23901.1, GB/T 23901.2, GB/T 23901.5.

When the penetration conditions of the level B technology cannot be met, due to technical or structural reasons (such as the type of radiation source, the source-to-target distance, etc.), it may use the penetration conditions, which are specified by the level A technology, after agreed by the parties to the contract; it shall take compensation measures for the sensitivity loss. For CR detection technology, it shall increase the minimum gray value and SNR_N compensation. For DDA detection technology, it shall increase the SNR_N (recommended 1.4 times the SNR_N) compensation. If the sensitivity of the image quality indicator, which is specified by the level B technology is reached, the object can be considered to be transilluminated according to the level B technology. For the penetration layout of 7.1.4 and 7.1.5, if the source-to-detector distance is reduced according to 7.6, there is no need to perform sensitivity compensation according to the above method.

5.2 Compensation rules

5.2.1 General

Compensation rules are divided into compensation rule I (CP I), compensation rule II (CP II), compensation rule III (CP III) (see 5.2.2 ~ 5.2.4), to ensure that the digital detector achieves sufficient contrast, to improve detection sensitivity.

The purpose of using the compensation rule is to obtain the smallest $CNR_N/\Delta w$, that is, the normalized basic spatial resolution of the digital detector, based on the thickness difference Δw of the detectable material. When the $CNR_N/\Delta w$ does not meet the requirements, due to insufficiency of one of the following parameters, it can be compensated by increasing SNR.

5.2.2 CP I

For insufficient contrast (such as caused by increased tube voltage), compensate by increasing SNR (such as by increasing tube current or exposure time).

5.2.3 CP II

In view of the large inherent unsharpness of the detector (SR_b value is greater than the specified value), it is compensated by increasing the SNR [by increasing the conventional wire-type image quality value (or stepped hole-type

6.4 Digital image identification

On each penetrated section of the tested object, it shall be placed with an identification mark, which is composed of letters, numbers, symbols, such as: product number, weld number, repair mark, penetration date, etc., to characterize the information of the object and location, to which the detection image belongs. The marked image shall be located outside the effective evaluation area; it shall ensure that each segment is clearly and correctly marked.

6.5 Marking of object

The surface of the object should be permanently marked, to ensure the accurate positioning of each digital image (for example: zero point, direction, marking, size, etc.).

If the nature of the material or the conditions of use do not allow permanent marking on the surface of the object, it can be recorded by means of penetration diagrams or photographs.

6.6 Digital image overlap

When more than two digital images are used in the penetration area, each digital image shall have a certain overlap area, to ensure that the entire tested area is penetrated. The high-density overlap mark shall be placed on the surface of the object, in the overlap area; it can be displayed on each digital image.

6.7 Minimum image quality value

The minimum image quality requirements for digital radiographic testing of metal material welds are as shown in Table A.1 ~ Table A.14 in Appendix A. The image quality requirements, for digital radiographic testing of other materials, shall be determined by the parties to the contract, in accordance with GB/T 23901.4.

When Ir192 or Se75 is used for testing, when the image quality value cannot meet the requirements of Table A.1 ~ Table A.12, the following requirements can be implemented, as agreed by the parties to the contract:

Double-wall double-shadow penetration technology, level A and level B ($w = 2t$):

- Use Ir192, $10\ mm < w \leq 25\ mm$, it allows image quality value minus 1;

- Use Se75, $5\ mm < w \leq 12\ mm$, it allows image quality value minus 1.

Single-wall single-shadow and double-wall single-shadow penetration

technology, level A:

- Use Ir192, 10 mm < w ≤ 24 mm, it allows image quality value minus 2;

- Use Ir192, 24 mm < w ≤ 30 mm, it allows image quality value minus 1;

- Use Se75, 5 mm < w ≤ 24 mm, it allows image quality value minus 1.

Single-wall single-shadow and double-wall single-shadow penetration technology, level B:

- Use Ir192, 10 mm < w ≤ 40 mm, it allows image quality value minus 1;

- Use Se75, 5 mm < w ≤ 20 mm, it allows image quality value minus 1.

6.8 Types and use of image quality indicators

6.8.1 Types of image quality indicators

Use GB/T 23901.1 (wire-type image quality indicator), GB/T 23901.2 (step-hole type image quality indicator) or GB/T 23901.5 (duplex-wire type image quality indicator), to determine the image quality of digital radiography.

6.8.2 Use of duplex-wire image quality indicator

In order to determine the basic spatial resolution of the digital detector system AND verify whether the system hardware meets the requirements of Table A.13 and Table A.14, it requires a reference image. The image is produced in accordance with Appendix B. The duplex-wire image quality indicator shall be placed directly on the surface of the digital detector.

When performing digital radiographic detection on an object, it is not mandatory to use a duplex-wire image quality indicator for digital image quality measurement. When a wire-type image quality indicator and a duplex-wire image quality indicator are required, to measure the digital image quality, at the same time, it can be determined, through negotiations by various parties to the contract. The duplex-wire image quality indicator shall be placed on the side surface of the object's ray source; the measurement of the image spatial resolution shall be carried out, in accordance with Appendix B. The penetration thickness, which is corresponding to the measured image spatial resolution value, shall meet the requirements of Table A.13 or Table A.14. The single-wall single-shadow penetration thickness corresponds to the nominal thickness of the object. During testing by the double-wall double-shadow penetration (Figure 11 or Figure 12), the duplex-wire image quality indicator is placed on the side surface of the tube ray source; the outer diameter of the tube is taken as the penetration thickness. Determine whether the measured image spatial resolution meets the requirements, according to Table A.13 or Table A.14. For

placing an image quality on the side of the ray source AND the side of the digital detector, respectively; observe the resulting image, under the same penetration conditions, to determine the image quality value. When a filter is installed on the front end of the digital detector, which is used for detection, the image quality indicator shall be placed in front of the filter. When using the double-wall penetration AND the image quality indicator is placed on the side of the digital detector, there is no need for comparison test. At this time, the image quality value is determined according to Table A.9 ~ Table A.12.

When the image quality indicator is placed on the side of the digital detector, the type "F" shall be placed close to the image quality indicator AND indicated in the testing report.

If relevant measures are taken to ensure that the same penetrated part, of the test object or area, is subjected to digital radiographic testing, by the use of the same penetration parameters and penetration technology, meanwhile there is no difference in the contrast sensitivity of the obtained images, it is not necessary to determine the contrast sensitivity on each digital image. The determination requirements for the specific image's contrast sensitivity should be negotiated by the parties to the contract.

For tube butt welds, which have an outer diameter greater than or equal to 200 mm, when using the ray source center method for circumferential penetration, it should place at least three image quality indicators, at equal intervals in the circumferential direction.

6.9 Personnel qualifications

The personnel who carry out radiographic testing, according to this part, shall be qualified and certified, in accordance with GB/T 9445 OR agreed by the parties to the contract; obtain the qualification level certificate of the relevant industrial category of radiographic testing; be subject to professional job training and authorization, by the employer or its agent. At the same time, the testing personnel shall be able to prove that, he has experienced the training and qualification appraisal for additional industrial digital radiographic testing technology.

7 Recommended digital radiography technology

7.1 Penetration method

7.1.1 General

Under normal circumstances, the digital radiographic testing technology for welds shall be implemented, in accordance with the provisions of Figure 1 ~ Figure 19 in 7.1.2 ~ 7.1.9.

For the tube butt joint's girth weld, which has an outer diameter D_e of greater than 100 mm, or the nominal thickness t of greater than 8 mm, or the weld width of greater than $D_e/4$, it should not use the double-wall double-shadow elliptical penetration technique of Figure 11. When penetrated by the double-wall double-shadow ellipse, if t/D_e is less than 0.12, it is penetrated 2 times at 90° apart; if the conditions are not met, it is penetrated 3 times at 120° or 60° apart. The maximum distance between the elliptical images shall be approximately one weld width.

For the tube butt joint's girth weld, which has an outer diameter D_e of less than 100 mm, if there is difficulty in penetration by the double-wall double-shadow ellipse, the vertical penetration technology (see Figure 12) can be used for 3 times of penetration, at 120° or 60° apart, according to 7.1.7.

When using the penetration layout of Figure 11, Figure 13, Figure 14, the incident angle of the ray beam shall be as small as possible; however, the overlap of the upper and lower weld images shall be prevented. Under the premise of meeting 7.6, when using the penetration layout in Figure 13, the source-to-object distance f shall be as small as possible. The image quality indicator and type "F" shall be placed, close to the digital detector.

Due to the difference in the geometry of the object or the thickness of the material, it may use other penetration techniques, as agreed by the parties to the contract. One of the methods is given in 7.1.9. In addition, the same material can be used for thickness compensation.

Note: See Appendix C, for the number of exposures, which are required for 100% penetration of butt-joint's girth welds.

If geometric magnification penetration technology is not used, the digital detector shall be placed as close to the object as possible.

If the curved digital detector cannot be used, the use of the flat digital detector array is as shown in Figure 2b), Figure 8b), Figure 13b), Figure 14b). The source-to-detector distance SDD shall calculated, from the wall thickness t, the maximum distance b from the detector to the surface of the object on the side of the ray source, the focal point or the size of the ray source d, according to formulas (6) and (7) in 7.6.

7.1.2 Single-wall penetration method

The ray source is located on one side of the tested object, whilst the digital detector is located on the other side, as shown in Figure 1.

eccentric penetration method (see 7.1.5), the allowable reduction of the minimum source-to-object distance should not exceed 20% of the specified value. When using the central penetration method (see Figure 5 of 7.1.4), the allowable reduction of source-to-target distance shall not exceed 50% of the specified value. On the premise that the image quality meets the requirements, the source-to-object distance can be further reduced, as agreed by the parties to the contract.

7.7 Geometric magnification technology

For CR and digital detector array DDA radiographic testing systems, compared with the seam radiographic fine grain film which has high spatial resolution, one of the application difficulties is that, digital detectors or most IP plate scanners have larger pixel size (greater than 50 μm), which may cause that, the image contrast sensitivity and spatial resolution cannot meet the specified requirements. The method to overcome the difficulty of this application is to use advanced digital detector array DDA, which has good performance consistency, to solve it by improving the digital image SNR_N OR using geometric magnification penetration technology.

Note: The geometric magnification is not the magnification of the image display zoom. Appropriate geometric magnification may reduce the unsharpness of the image.

If the image quality value of the digital image (verified by wire-type image quality indicator or step-hole-type image quality indicator) AND the spatial resolution (verified by duplex-wire image quality indicator, see Appendix B) cannot meet the requirements of Table A.1 ~ Table A.14, it may follow the requirements of 7.3.2 (CPII), to compensate the loss of detection sensitivity and spatial resolution, by increasing the image's signal-to-noise ratio.

Another method is to use geometric magnification penetration technology, that is, use a small-sized ray source or an X-ray tube with a small focal point, to increase the distance between the object and the IP plate or digital detector array DDA.

If the required image quality is still not achieved, by the above two measures, the CR or digital detector array DDA's ray detection system cannot be applied to the object detection.

When determining whether the magnification is appropriate, the duplex-wire image quality indicator shall be used, to verify the spatial resolution (or unsharpness) of the duplex-wire image quality indicator, which is displayed in the digital image of the object. If 2 times the basic spatial resolution $SR_b^{detector}$ is greater than the ray source size or focus size d, THEN, the duplex-wire image quality indicator shall be placed on the digital detector side of the object; otherwise, the duplex-wire image quality indicator shall be placed on the source

placed directly on the surface of the object (see 7.7). At this time, the image spatial resolution value shall be less than or reach the requirements of Table A.13 or Table A.14. If the basic spatial resolution or image spatial resolution, of the digital detector array DDA, is higher than the requirements of Table A.13 or Table A.14, it can be compensated according to 7.3.2 (CP II).

If the digital detector array DDA or IP plate is used, to measure the size of the defect, in the digital image, it shall obtain a digital image with a higher SNR_N. The specific requirements shall be negotiated by the parties to the contract. A higher SNR_N can compensate for the increase in local unsharpness, which is caused by the insertion of bad pixels.

The bad pixels in the digital detector array DDA shall be evaluated regularly.

Note: By comparing with CP II, the significantly improved SNR_N compensates for the increase in local unsharpness, which is caused by the insertion of bad pixels. This is considered to be CP III.

7.9.4 Image processing

The digital detection image shall be evaluated, by a certain gray-scale gray value representation method; its gray value is proportional to the radiation dose, which is received by the detector. The ideal digital detection image shall be evaluated for signal-to-noise ratio, spatial resolution, SNR_N. Through interactive adjustment of contrast and brightness, the digital detection image has the best display. The detection software shall generally be integrated with integrated noise reduction, modulation transfer function curve measurement (SR_b measurement), signal-to-noise ratio or SNR_N measurement tools, for the evaluation of digital image quality. For important image analysis, the electronic zoom function shall be used, to realize the image display from 1:1 (a digital image pixel is displayed as a display pixel) to 1:2 (a digital image pixel is displayed as four display pixels).

When the stored original image is displayed for further processing (such as high-pass or low-pass filtering), there shall be a clear record; it shall obtain the permission of the parties to the contract; it shall not modify the stored original image data.

If further image processing (such as high-pass or low-pass filtering) is to evaluate the wire-type image quality value or the step-hole-type image quality value, it shall use the same filter parameters, to evaluate the weld and the image quality indicator's image.

7.10 Digital image display and storage

The digital image shall be observed in a dark room. The display setting should be suitable for the display of the digital detection image.

The minimum conditions for digital image display observation shall meet the requirements of a) ~ d):

a) Minimum brightness: 250 cd/m^2;

b) Minimum display gray level: 256;

c) The minimum displayable brightness ratio: 1:250;

d) Minimum display pixels: 106, pixel size < 0.3 mm.

The digital detector detection system shall have sufficient resolution, to meet the storage of digital original images. Before digital original images are stored, only image processing, which is related to digital detector correction (such as offset correction, gain correction, bad pixel correction), is allowed, as shown in ASTM E2597[3]). The recommended original image storage format is DICOM or DICONDE, to ensure that the stored original image cannot be changed.

The digital original images, in the digital detector detection system, shall be backed up regularly, for long-term storage. The compression method, which is used in the backup storage, shall not lose the original data.

8 Testing report

After the digital radiographic testing, it shall record the testing results and relevant testing parameters in detail; fill the testing report, so that the testing results can be inquired under any circumstances.

The testing report shall contain at least the following information:

a) Testing organization;

b) The name of the object;

c) Material;

d) Heat treatment status;

e) The groove form of the weld;

f) Nominal thickness;

g) Welding method;

h) Testing criteria, including acceptance requirements;

i) Digital radiographic testing technology and level, including image quality indicators and required image quality values;

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