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**Nondestructive Testing of Pressure Equipment – Part 14:
Computed Radiographic Testing**

承压设备无损检测 第 14 部分：射线计算机辅助成像检测

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Nondestructive Testing of Pressure Equipment – Part 14: Computed Radiographic Testing

1 Scope

1.1 This Document specifies the radiographic computer-aided imaging inspection technology and quality grading requirements for fusion welding joints of metal material pressure components of pressure-bearing equipment. Metal materials used to make welding joints include steel, copper and copper alloys, aluminum and aluminum alloys, titanium and titanium alloys, nickel and nickel alloys.

1.2 This Document is applicable to the radiographic computer-aided imaging inspection of butt welds of plates and tubes (hereinafter referred to as "butt welds") during the manufacture, installation and in-service inspection of pressure components of pressure-bearing equipment.

1.3 The imaging device applicable to this Document is the imaging plate.

1.4 The radioactive source applicable to this Document is the X-ray source and the Ir192 and Se75 γ radioactive source, where the maximum tube voltage of the X-ray machine does not exceed 600kV.

1.5 The radiographic computer-aided imaging inspection of welding joints of pressure-bearing equipment supports and structural parts and plug-in and placement tubes can be used as a reference.

2 Normative References

The provisions in following documents become the essential provisions of this Document through reference in 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 Document.

GB/T 14058 Apparatus for gamma radiography

GB/T 21356 Non-destructive testing - Qualification and long-term stability of computed radiology systems

GB/T 23901.1 Non-destructive testing - Image quality of radiographs - Part 1: Determination of the image quality value using wire-type image quality indicators

spacing of the laser scanner scanning the imaging plate, and the ratio of the laser point scanning speed to the operating frequency of the analog-to-digital converter.

3.16 Signal-to-noise ratio (SNR)

In a digital image, the ratio of the linearized grey mean to the standard deviation of a selected area.

3.17 Normalized signal-to-noise ratio (SNR_n)

Signal-to-noise ratio that is normalized based on resolution ratio.

3.18 Penetrated thickness (W)

The nominal thickness of the material in the direction of the ray penetration. In case of multi-layer penetration, the penetrated thickness is the sum of the nominal thickness of each layer of material.

3.19 Effective length of a single exposure

The maximum effective testing length of a single exposure is in accordance with the standard.

3.20 Ratio between max. and min. penetrated thicknesses (K)

The ratio of the maximum thickness and the minimum thickness of the parent material that the radiation beam penetrates within an effective length of a single exposure is also called the ratio between max. and min. penetrated thicknesses.

3.21 Digital image processing

Methods and techniques for processing digital images by computers.

3.22 Standard sample

A specimen of known size that is used to calibrate the size of features in an image.

3.23 Raw image

The image that is formed by the latent image on the imaging plate is scanned by a scanner.

3.24 Round flaw

Volume defects such as pores, slag inclusions and tungsten inclusions with an aspect ratio of no more than 3.

3.25 Stripy flaw

Volume defects such as pores, slag inclusions and tungsten inclusions with an aspect ratio of

requirements. The system performance testing conditions and testing methods shall be implemented in accordance with the provisions of GB/T 21356. The system shall at least meet the following performance indicators:

- a) The image geometric distortion rate shall be less than $\pm 2\%$;
- b) There shall be no jitter or sliding between the scanner and the imaging plate, or the jitter shall be lower than the system noise level;
- c) On the same horizontal line of the image, the grey change rate between the center area and the edge background shall not exceed $\pm 10\%$;
- d) Other performance indicators include signal-to-noise ratio, laser beam function, shadow, image erasure, artifacts, etc.

4.2.3.1 Imaging plate

The supplier shall provide the quality certification documents of the imaging plate, which shall at least include the type and specifications, excitation response time, chemical composition and other main performance parameters of the imaging plate. Users shall use and store it according to the temperature and humidity conditions recommended by the manufacturer, and avoid unnecessary exposure.

4.2.3.2 Scanner

The supplier shall provide the quality certification documents of the scanner, which shall at least include the specifications, scanning size, photomultiplier tube voltage or gain, scanning resolution ratio, laser beam focus size and other main performance parameters; and its functions and performance shall at least meet the following requirements:

- a) The scanner shall have the scanning and erasing functions, and the residual latent image grey value after erasing shall not exceed 5% of the maximum greyscale of the system;
- b) The scanning laser power shall meet the requirements of signal acquisition;
- c) The photomultiplier tube voltage or gain and scanning resolution ratio of the scanner shall be adjustable;
- d) The laser beam shall be free of vibration, and there shall be no artifacts or scanning line loss.

4.2.4 Computer system

The basic configuration of the computer system is determined according to the performance and scanning speed requirements of the adopted CR system. It should be equipped with a memory of no less than 512MB, a hard disk of no less than 40GB, a high-brightness and high-resolution ratio display, a CD writer, a network card, etc.

The display shall meet the following minimum requirements:

- a) Minimum brightness of 250 cd/m²;
- b) The display has at least 256 grey levels;
- c) The minimum displayable light intensity ratio is 1:250;
- d) The display has at least 1M pixels and the pixel size is less than 0.3 mm.

4.2.5 System-specific software

4.2.5.1 The system software is the core unit of the computed radiographic testing system, which controls the scanner to complete the conversion of the imaging plate acquisition information to the digital image, as well as the functions of latent image erasure, image storage, auxiliary evaluation, and annotation, etc.

4.2.5.2 It should have the function of converting multiple image formats.

4.2.5.3 It shall have the measurement functions of greyscale, resolution ratio, signal-to-noise ratio, geometric dimensions, etc.

4.2.5.4 It shall have functions such as greyscale conversion, contrast and brightness adjustment, and image zoom, etc.

4.2.5.5 It shall have the functions of browsing and searching for information related to the collected image.

4.2.5.6 The test report can be automatically generated.

4.2.6 Image quality indicator

4.2.6.1 The image quality indicators used in this Document include wire type image quality indicators and duplex wire type image quality indicators. The supplier of the image quality indicator shall provide corresponding quality certification documents.

4.2.6.2 Wire type image quality indicator

- a) The wire type image quality indicator is used to measure image sensitivity, including general wire type image quality indicator and equal-diameter wire type image quality indicator. Its model and specification shall comply with the provisions of GB/T 23901.1 and JB/T 7902, respectively;
- b) The material code, material of the wire type image quality indicator, and material range of inspected object applicable to the wire type image quality indicators made of different materials shall be as specified in Table 1. The absorption coefficient of the wire type image quality indicator shall be the same as or similar to that of the tested material, and

4.3 Testing technology level

4.3.1 The computed radiographic testing technology level specified in this Document is divided into three levels from low to high: A, AB and B.

4.3.2 The selection of the testing technology level shall meet the requirements of relevant laws, regulations, standards and design technical documents, and shall also meet other technical requirements agreed upon by the contracting parties. For the butt welds of pressure-bearing equipment, it is generally recommended to use Level-AB testing technology for testing. For important equipment and structures, as well as butt welds made of special materials and special welding processes, Level-B testing technology should be used for testing.

4.3.3 When certain testing conditions cannot meet the requirements of Level-AB (or Level-B) testing technology, the contract parties agree that, on the premise of effective compensation measures (such as increasing exposure or selecting a CR system with a higher signal-to-noise ratio, etc.) is taken, if the image quality reaches the requirements of Level-AB (or Level-B) testing technology, it can be considered that the testing is carried out according to Level-AB (or Level-B) testing technology.

4.3.4 If the source-to-object distance f does not meet the requirements of 5.6 during the testing, the provisions of 4.3.3 are not applicable.

4.3.5 When certain conditions for the testing of pressure-bearing equipment cannot meet the requirements of Level-AB testing technology, the contract parties agree that, on the premise of effective compensation measures (such as increasing exposure or selecting a system with a higher signal-to-noise ratio, etc.) is taken, Level-A testing technology can be used for testing; and other non-destructive testing methods should be used for supplementary testing at the same time.

4.4 Testing process documents

4.4.1 Testing process documents include process procedures and operating instructions.

4.4.2 In addition to meeting the requirements of NB/T 47013.1, the process procedures shall also specify the specific scope or requirements of the following related factors. If the changes in related factors exceed the provisions, the process procedures shall be re-compiled or revised.

- a) Applicable structure, material type and thickness;
- b) Radioactive source energy range and focal size;
- c) Testing technology level;
- d) Testing process (transillumination method, transillumination parameters, geometric parameters);
- e) Testing equipment (type, specification, main technical parameters);

f) Image quality requirements.

4.4.3 The operation instructions shall be prepared according to the contents of the process specification and the testing requirements of the inspected object. In addition to meeting the requirements of NB/T 47013.1, the contents shall at least include:

- a) Testing equipment: radioactive source (type, specification, focus or source size), imaging plate and scanner (type, specification), testing software, metal screen (type and thickness), image quality indicator (type and model), backscatter shielding lead plate, marking, standard sample, etc.
- b) Testing technology level.
- c) Testing process: transillumination method, transillumination parameters (including tube voltage, exposure), geometric parameters, scanner parameters.
- d) Testing mark.
- e) Image quality requirements: grayscale range, image resolution ratio, image sensitivity, normalized signal-to-noise ratio.
- f) Acceptance standard.
- g) Process verification image No.

4.4.4 Process verification

4.4.4.1 The operating instructions for the first use shall be subject to process verification to verify whether the image quality can meet the specified requirements in the standard.

4.4.4.2 Process verification can be carried out by using a comparison specimen through a special transillumination test, or by using the first batch of images of the product as the basis for verification. In both cases, the verification images used as the basis shall be marked.

4.4.4.3 The placement of the radioactive source shall be ensured to be consistent with the actual test.

4.4.4.4 wire type and duplex wire type image quality indicators shall be placed; and the placement of the wire type image quality indicator shall be consistent with the actual test.

4.4.4.5 The duplex wire type image quality indicator shall be placed on the parent material of the inspected object close to the weld, with the angle between the length direction and the row or column of the detector being $2^{\circ}\sim 5^{\circ}$; and the Value-*b* being larger. When the material types of the weld are different, it shall be placed on the surface of the inspected object of the material with the largest attenuation coefficient. The placement orientation is shown in the example of Figure 1 (positive film); and the image resolution ratio in the four directions of the top, bottom, left and right of the imaging center area shall meet the requirements. When using the center

transillumination is performed for 2 times at 90° intervals; when $T/D_0 > 0.12$, transillumination is performed for 3 times at 120° or 60° intervals. When vertical transillumination overlapping imaging is performed, transillumination shall generally be performed for 3 times at 120° or 60° intervals.

When multiple transilluminations are performed according to the above provisions, the overlap of the effective evaluation areas of adjacent images shall ensure that the entire volume range of the detected area is covered; if the minimum number of exposures cannot meet the 100% coverage requirement, the number of exposures shall be increased.

5.5.5.3 Special cases

Due to structural reasons, it is not possible to perform multiple transilluminations at the interval angles specified in 5.5.5.2. After agreement between the contracting parties, the transillumination interval angles specified in 5.5.5.2 may no longer be enforced, but measures shall be taken to expand the detectable range of defects as much as possible. At the same time, the image quality within the evaluation range shall be guaranteed to meet the requirements of this Document, and the relevant situation shall be explained in the test report.

5.5.5.4 Local testing

The number of transilluminations of small-diameter tube circumferential welds that do not require 100% testing shall be agreed upon by the contracting parties, and relevant records shall be kept.

5.6 Minimum source-to-object distance

5.6.1 The select source-to-object distance f shall meet the following requirements:

- Level-A testing technology: $f \geq 7.5d \cdot b^{2/3}$;
- Level-AB testing technology: $f \geq 10d \cdot b^{2/3}$;
- Level-B testing technology: $f \geq 15d \cdot b^{2/3}$.

Figure 2 is a nomogram for determining f using the Level-A and Level-B CR testing techniques; and Figure 3 is a nomogram for determining f using the Level-AB CR testing techniques. The effective focus or source size d is calculated in accordance with the provisions of NB/T 47013.2.

5.6.2 When the radioactive source is used for circumferential exposure in the central transillumination method in the object to be tested, if the image quality meets the requirements of 5.16, the Value- f may be reduced, but the reduction value shall not exceed 50% of the specified value.

5.6.3 When the radioactive source is used for eccentric transillumination in the object to be tested, if the image quality meets the requirements of 5.16, the Value- f may be reduced, but the reduction value shall not exceed 20% of the specified value.

back of the dark box. Generally, the height of the "B" lead mark is 13 mm and the thickness is 1.6 mm. The transillumination and scanning are carried out according to the requirements of the testing process. Take the negative film as an example: if a light-colored "B" image appears on the diagram, it means that the back scattering protection is insufficient and the thickness of the lead plate for back scattering protection shall be increased. If the "B" image does not appear on the diagram or a dark-colored "B" image appears, it means that the back scattering protection meets the requirements.

5.10.2.3 When the back scattering protection does not meet the requirements, a lead plate can be used on the back of the imaging plate and outside the dark bag to absorb the scattered rays. The thickness of the lead plate shall be based on whether the back scattering inspection meets the requirements.

5.10.3 When ^{75}Se and ^{192}Ir γ -ray sources are used and there is edge scattering, a lead filter plate can be placed between the object and the dark box to filter out the scattered rays. Depending on the different penetrated thicknesses, the thickness of the filter plate should be 0.2mm~1mm.

5.11 Use of wire type image quality indicator

5.11.1 Principles of placing wire type image quality indicator

The wire type image quality indicator shall generally be placed at one end of the weld (approximately 1/4 of the length of the detected area); the metal wire shall cross the weld; and the thin wire shall be placed on the outside. When multiple welds are simultaneously transilluminated on an imaging plate, the wire type image quality indicator shall be placed at the weld at the edge of the transillumination area.

The placing of wire type image quality indicator should also comply with the following provisions:

- a) Single-wall transillumination image quality indicator is placed on the radioactive source side. Double-wall single-shadow transillumination image quality indicator is placed on the imaging plate side. Double-wall double-shadow transillumination image quality indicator can be placed on the radioactive source side or on the imaging plate side.
- b) In single-wall transillumination, if the image quality indicator cannot be placed on the radioactive source side, it is allowed to be placed on the imaging plate side.
- c) When the image quality indicator is placed on the imaging plate side in single-wall transillumination, a comparative test shall be carried out. The comparative test method is to place an image quality indicator on both the radioactive source side and the imaging plate side; and use the same conditions as the object to transilluminate; and measure the sensitivity difference between the image quality indicators placed on the radioactive source side and the imaging plate side; so as to correct the sensitivity and ensure that the sensitivity of the actual transillumination image meets the requirements.

- d) When the image quality indicator is placed on the imaging plate side, the lead word "F" shall be placed at an appropriate position on the image quality indicator as a mark. The image with the "F" mark shall appear on the diagram at the same time as the mark of the image quality indicator; and it shall be noted in the test report.

5.11.2 Number of wire type image quality indicators

In principle, there shall be an image of the image quality indicator on each diagram. When multiple imaging plates are imaged in one exposure, the number of the used image quality indicators is allowed to be reduced, but it shall meet the following requirements:

- a) When the circumferential exposure of the circumferential weld is placed in the center of the radioactive source, at least 3 image quality indicators are placed at equal intervals on the circumference;
- b) When multiple imaging plates are arranged continuously in one exposure, at least one image quality meter is placed on the first, middle and last imaging plates, respectively.

5.11.3 Wire type image quality indicator used in butt welds of small diameter tube and its placing requirements

When using general wire type and special equal-diameter wire type image quality indicators for small diameter tubes, the metal wire shall be placed perpendicular or parallel to the weld.

5.11.4 Butt welds between materials of different thicknesses or different types

If the geometry of the weld allows, the parts with different thicknesses or different material types shall use wire type image quality indicators that match the thickness or type of the object to be tested, and place them in the corresponding parts of the weld.

5.11.5 If the wire type image quality indicator cannot be placed in the specified position, a comparison specimen shall be used instead of the object to be tested; and the thickness of the comparison specimen shall be the maximum thickness of the object to be tested. Its image sensitivity shall comply with the provisions of 6.2, and relevant instructions and records shall be kept.

5.11.6 Image recognition of wire type image quality indicator

5.11.6.1 When using a wire type image quality indicator, the number of the thinnest line that can be identified on the diagram is the sensitivity value of the image quality indicator. When the continuous visible length of the metal wire image in the uniform greyscale area (generally the parent metal area adjacent to the weld) of the diagram is no less than 10mm, the line shall be considered identifiable.

5.11.6.2 The dedicated equal-diameter wire type image quality indicator shall be able to identify at least two metal wires.

5.13.6 Identification marks are allowed to be placed on the radioactive source side or the imaging plate side. The images of all marks shall not overlap and shall not interfere with the image of the effective evaluation area.

5.13.7 In order to accurately identify the actual testing position, the permanent mark or part on the object to be tested shall be used as a reference point; when permanent marking cannot be performed due to material properties and usage conditions, other methods (such as transillumination arrangement diagram) shall be used to determine.

5.14 Standard sample

5.14.1 The standard sample is used as a size calibration sample when measuring features (defects) in the diagram. For specific use, see 7.2.

5.14.2 The standard sample shall be placed on the imaging plate side. The length direction of the standard sample shall be parallel to the weld direction. The image shall be formed within the effective evaluation range and shall not interfere with the image within the effective evaluation area.

5.14.3 The length of the standard sample shall be no less than 15 mm.

5.15 Selection of scanner parameter

5.15.1 The selection of the scanner photomultiplier tube voltage or gain shall match the exposure so that the grey value of the digital image is in an appropriate range (5%~90%).

5.15.2 The selection of the scanning resolution ratio shall ensure that the image resolution ratio meets the requirements specified in the standard and shall match the characteristics of the imaging plate.

5.16 Image evaluation environment requirements

Image evaluation shall be carried out in a dedicated evaluation room, which shall be clean and tidy, with appropriate temperature and humidity.

6 Image Quality Requirements

6.1 General requirements

6.1.1 The marked image on the diagram shall be displayed complete and correctly positioned. There shall be no pseudo-defect images caused by scratches, indentations, folds, delamination, foreign matter adhesion, and metal screen defects that interfere with defect identification in the effective image evaluation area.

6.1.2 The quality of the object to be tested can only be graded after the image quality meets the specified requirements.

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