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NATIONAL STANDARD OF THE
PEOPLE'S REPUBLIC OF CHINA

ICS 77.040.20

CCS H 26

GB/T 40385-2021 / ISO 10893-7:2019

**Non-destructive testing of steel tubes - Digital radiographic
testing of the weld seam of welded steel tubes for the
detection of imperfections**

钢管无损检测 焊接钢管焊缝缺欠的数字射线检测

(ISO 10893-7:2019, Non-destructive testing of steel tubes - Part 7: Digital
radiographic testing of the weld seam of welded steel tubes for the detection
of imperfections, IDT)

Issued on: August 20, 2021

Implemented on: March 01, 2022

**Issued by: State Administration for Market Regulation;
Standardization Administration of the People's Republic of China.**

Table of Contents

Foreword	3
1 Scope	5
2 Normative references	5
3 Terms and definitions	6
4 General requirements	7
5 Test equipment	8
6 Test method.....	9
7 Image quality	12
8 Image processing	18
9 Classification of indications	19
10 Acceptance limits.....	19
11 Acceptance	20
12 Image storage and display.....	20
13 Test report	21
Appendix A (Informative) Examples of distribution of imperfections	22
References	24

Non-destructive testing of steel tubes - Digital radiographic testing of the weld seam of welded steel tubes for the detection of imperfections

1 Scope

This document specifies the requirements for X-ray digital testing techniques of the longitudinal weld seam or helical weld seam of automatic fusion arc-welded steel tubes for the detection of imperfections, including the radiographic testing of computed radiography (CR) or digital detector arrays (DDAs). This document also specifies the acceptance levels and calibration procedures of digital radiographic testing.

This document also applies to the testing of circular hollow sections.

Note: The digital radiographic testing method is used as an alternative of film-based radiographic X-ray testing, as shown in ISO 10893-6^[8].

2 Normative references

The following documents are normatively referenced in this document and are indispensable for its application. For dated references, only the version corresponding to that date is applicable to this document; for undated references, the latest version (including all amendments) is applicable to this document.

ISO 5576, Non-destructive testing - Industrial X-ray and gamma-ray radiology - Vocabulary

ISO 9712, Non-destructive testing - Qualification and certification of NDT personnel

ISO 11484, Steel products - Employer's qualification system for non-destructive testing (NDT) personnel

ISO 17636-2:2013, Non-destructive testing of welds - Radiographic testing - Part 2: X- and gamma-ray techniques with digital detectors

ISO 19232-1, Non-destructive testing - Image quality of radiographs - Part 1: Determination of the image quality value using wire-type image quality indicators

ISO 19232-2, Non-destructive testing - Image quality of radiographs - Part 2: Determination of the image quality value using step/hole-type image quality indicators

ISO 19232-5, Non-destructive testing - Image quality of radiographs - Part 5: Determination of the image unsharpness and basic spatial resolution value using duplex wire-type image quality indicators

3 Terms and definitions

Terms and definitions determined by ISO 5576 and ISO 11484, as well as the following, are applicable to this document.

3.1 Tube

Hollow elongated product, open at both ends, of any cross-sectional shape.

3.2 Welded tube

Tube (3.1) made by welding together adjacent edges of a flat rolled product. After welding, it can be processed by cold working or hot working to obtain the final dimensions.

3.3 Manufacturer

Organization that produces and manufactures products in accordance with relevant standards and declares the conformity of the delivered products with all applicable provisions of the standards.

3.4 Agreement

Contractual agreement between the manufacturer (3.3) and the purchaser at the time of enquiry and order.

3.5 Signal-to-noise ratio

SNR

S/N

Ratio of the average value of the linearized grey values TO the standard deviation of the linearized grey values (noise) in a given region in a digital image.

[Source: ISO 17636-2:2013, 3.10, modified: The symbol S/N is added.]

3.6 Spatial basic resolution of a digital detector

R_{bS}^{detector}

The employer shall issue a testing (operation) authorization according to a written procedure. The non-destructive testing (NDT) shall be authorized by a level 3 NDT personnel approved by the employer.

Note: The definitions of levels 1, 2 and 3 personnel are shown in relevant standards such as ISO 9712 and ISO 11484.

4.3 The tube under test shall be straight enough and shall be free of foreign matters, so as to ensure the validity of the test. Surfaces of the weld seam and the adjacent base material shall be free of foreign matters and surface irregularities, which may interfere with the interpretation of the radiographic testing.

To gain an acceptable surface quality of the finished product, surface grinding is permitted.

4.4 When the weld reinforcement is removed, markers (usually lead arrows) shall be placed on both sides of the weld seam, so that the position of the weld seam can be identified on the radiographic image; alternatively, an integrated automatic positioning system can be used to identify the position of the weld seam.

4.5 Usually, the identification symbol, in the form of lead letters, shall be placed on each part of the weld seam radiograph such that the lead letters are projected on the radiographic image, so that the weld seam of each part can be clearly identified in the radiographic image; alternatively, an integrated automatic positioning system can be used to identify the position of the tube weld seam corresponding to each radiographic image.

4.6 Marks shall be displayed on the radiographic images to provide accurate position reference points for each radiographic image; alternatively, the automatic measurement may be carried out on the digital image viewing screen by software to achieve accurate positioning of the image.

4.7 When the size of the detector is smaller than the length of the penetrated weld seam, the steel tube or the detector shall be moved in a step-by-step mode, and the digital radiographic testing shall be performed when the steel tube is not moving.

Warning – Exposure of any part of the human body to X-rays can be highly injurious to health. Wherever X-ray equipment is used, appropriate safety measures shall be applied. National safety precautions shall be strictly applied.

5 Test equipment

The following digital imaging methods can be used instead of the radiographic film testing:

- a) Computed radiography (CR) using storage fluorescent material imaging plates (such as EN 14784-1^[21] or GB/T 21355^[1], EN 14784-2^[22] or GB/T 26642^[2]);
- b) Radiology using digital detector arrays (such as ASTM E2597-07^[14] or GB/T 38240^[4], ASTM E2698^[15] or GB/T 35388^[3]);
- c) Digital radiographic testing method using image integration (such as EN 13068-1^[18] or GB/T 23909.1^[5], EN 13068-2^[19] or GB/T 23909.2^[6], EN 13068-3^[20] or GB/T 23909.3^[7]).

6 Test method

6.1 The digital radiographic testing technique specified in a) ~ c) of Chapter 5 shall be used to inspect the weld seam.

6.2 According to the provisions of ISO 17636-2, the image quality classes shall be divided into A and B:

- a) Class A: basic technique;
- b) Class B: enhanced technique.

Note: Class A imaging technique is used in most cases. Class B imaging technique is used when enhanced sensitivity is required to visualize all imperfections being detected.

The required image quality class should be specified in the relevant product standard.

6.3 The digital-to-image display shall meet the technical requirements of Class A or Class B.

6.4 During the testing, the beam of radiation shall be aimed at the center of the part of the weld seam under test and shall be perpendicular to the steel tube surface at this point.

6.5 Under the condition that the requirements of 6.9 and Chapter 7 are met, the diagnostic length shall be determined according to the following requirements: When the class B image quality is used, the penetrated thickness ratio at the end of the effective diagnostic length of the radiographic image shall not exceed 1.1; when the class A image quality is used, the penetrated thickness ratio at the end of the effective diagnostic length of the radiographic image shall not exceed 1.2.

6.6 The single-wall penetration technique shall be used. When the single-wall technique is not applicable due to the special size, the double-wall penetration technique can be adopted by negotiation under the condition that the required sensitivity is satisfied.

When using the detector-side image quality indicator for subsequent image acquisition, the previous exposure parameter settings (including X-ray source, detector and geometric arrangement) shall not be changed. For stable system and process settings (such as automated testing systems using DDAs), it is sufficient to verify the image quality once per shift as long as the steel pipe size, material and inspection parameters remain unchanged. In this case, only the source-side image quality indicator should be used to test the image quality.

The image unsharpness u_{im} shall be measured using a duplex wire-type image quality indicator conforming to ISO 19232-5.

The unsharpness is measured by the image of the duplex wire-type image quality indicator in the digital radiation; the unsharpness value is the smallest wire pair number (maximum wire diameter) when the modulation degree is less than 20%.

The duplex wire-type image quality indicator should be placed on the base metal at about 5° to the pixel direction of the weld image, to avoid image aliasing.

7.2 The spatial basic resolution of a digital detector, $R_{bs}^{detector}$, which is determined by manufacturing parameters and hardware parameters, shall be measured by a duplex wire-type image quality indicator placed in front of the detector; the $R_{bs}^{detector}$ shall be calculated according to Formula (3).

$$R_{bs}^{detector} = 0,5u_i \dots\dots\dots (3)$$

Compensation principle:

Where the image quality indicators in Table 1 or Table 2 (wire type, hole type, and duplex wire type) are used, if the detector system still does not meet the required IQI sensitivity, the sensitivity of single wire image quality indicator can be increased to compensate too high unsharpness values. The maximum limit of this compensation shall be level 3.

Example: For class B image quality, 10 mm wall thickness, wire W14 and duplex D11 are required. If D11 cannot be reached, compensation may be required: two steps down from D11 to D9, but two steps up from W14 to W16.

For a given penetration distance and tube voltage, the image contrast sensitivity of digital detectors depends on the penetration time and the tube current (mA), so, the increase of exposure time and tube current (mA) can increase the sensitivity of the single wire image quality indicator.

7.3 Two image quality classes are defined in Tables 1 and 2. For class A, the minimum normalized signal-to-noise ratio (S/N_{norm}) of the base metal should be greater than 70. For class B, the minimum normalized signal-to-noise ratio (S/N_{norm}) of the base metal should be greater than 100. The normalized signal-to-noise ratio

9 Classification of indications

9.1 All indications found on radiographic image shall be classified as weld imperfections or defects as defined in 9.2 and 9.3.

9.2 Imperfections refer to discontinuities of welds detected by the radiographic testing method specified in this document, the size and/or distribution density of which are within the specified acceptance limits, and have no practical impact on the intended use of the steel tube.

9.3 Defects are imperfections whose size and/or distribution density exceeds the specified acceptance limits. Defects may adversely affect or limit the intended use of the steel tube.

10 Acceptance limits

10.1 Unless alternative requirements are specified in the product standards, the acceptance limits specified in 10.2 ~ 10.6 are applicable to radiographic testing of the weld seam.

10.2 Where cracks, incomplete penetration and lack of fusion are found in the detection, the results shall be unqualified.

10.3 Individual circular slag inclusions and gas holes with a diameter not exceeding 3.0 mm or $T/3$ (whichever is the smaller, T is the nominal wall thickness of the steel tube) found during the testing are acceptable.

Within any 150 mm or $12T$ (whichever is the smaller) weld length range, when the spacing between individual inclusions is less than $4T$, the maximum cumulative diameter of all the above allowable individual imperfections shall not exceed 6.0 mm or $0.5T$ (whichever is the smaller).

10.4 Individual elongated slag inclusions, with a length not exceeding 12.0 mm or T (whichever is the smaller) or a width not exceeding 1.5 mm, found during the testing, are acceptable.

Within any 150 mm or $12T$ (whichever is the smaller) weld length range, when the spacing between individual inclusions is less than $4T$, the maximum cumulative length of all the above allowable individual imperfections shall not exceed 12.0 mm.

Note: For the limits specified in 10.3 and 10.4, refer to the figures in Appendix A.

10.5 Individual undercuts of any length, of which the maximum depth does not exceed 0.4 mm and the minimum wall thickness meets the requirements, are acceptable.

Individual undercuts within any 300 mm weld length, having a maximum length of $T/2$ and a maximum depth of 0.5 mm, and not exceeding 10% of the nominal wall thickness, are acceptable, provided that the number does not exceed two, and they are ground.

10.6 Undercuts of any length and depth, which are coincident on the inside and outside welds in the longitudinal direction, are acceptable.

11 Acceptance

11.1 Any tube not showing indications exceeding the corresponding acceptance limits shall be deemed to have passed this radiographic testing.

11.2 Any tube showing indications exceeding the corresponding acceptance limits shall be deemed suspect.

11.3 Suspect tubes shall be subjected to one or more of the following measures, and shall meet the requirements of the product standard:

- a) Grind the suspect area. Use magnetic particle or liquid penetrant to verify whether the defect is completely removed; re-examine the ground area by radiography. Adopt an appropriate method to measure the remaining wall thickness, to verify compliance with the specified deviations.
- b) Repair the suspect area by an approved welding procedure. Then, perform a radiographic testing of the repaired area in accordance with the requirements of this document and the corresponding product standard.
- c) Cut the suspect area. Measure the remaining length of the tube, to verify conformity with the specified length.
- d) Reject the suspect tube.

12 Image storage and display

The original images delivered by the detector system shall be stored in full resolution. Before storing the raw image, only the detectors related to image processing shall be calibrated [e.g., offset calibration, gain calibration for detector equalization and bad pixel calibration for detector images that provide no human intervention (see ASTM E2597-07^[14])]

The following minimum requirements shall be met when evaluating images:

- a) minimum brightness of 250 cd/m²;
- b) display of minimum 256 shades of grey;

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