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OF THE PEOPLE'S REPUBLIC OF CHINA

NB/T 47013.10-2015

Replacing JB/T 47013.10-2010

Nondestructive Testing of Pressure Equipments - Part 10: Ultrasonic Time of Flight Diffraction Technique

承压设备无损检测
第 10 部分：衍射时差法超声检测

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Contents

Foreword

This Standard "Nondestructive Testing of Pressure Equipments" (NB/T 47013) comprises the following 13 parts:

- Part 1: General Requirements;
- Part 2: Radiographic Testing;
- Part 3: Ultrasonic Testing;
- Part 4: Magnetic Particle Testing;
- Part 5: Penetrant Testing;
- Part 6: Eddy Current Testing;
- Part 7: Visual Testing;
- Part 8: Leak Testing;
- Part 9: Acoustic Emission Testing;
- Part 10: Ultrasonic Time of Flight Diffraction Technique;
- Part 11: Standard Practice for X-ray Digital Radioscopy;
- Part 12: Magnetic Flux Leakage Testing;
- Part 13: Pulsed Eddy Current Testing.

This Part is Part 10 of NB/T 47013: Ultrasonic Time of Flight Diffraction Technique.

This Part was drafted according to the rules given in "Directives for Standardization - Part 1: Structure and Drafting of Standards" (GB/T 1.1-2009).

This Part supersedes "Nondestructive Testing of Pressure Equipments - Part10: Ultrasonic Time of Flight Diffraction Technique" (NB/T 47013.10-2010); compared with NB/T 47013.10-2010, this Part has the following main technical changes:

- The relevant content of the chapter "Scope" was modified;
- Normative references were modified;
- Terminologies and definitions were added;
- Sequence of parts of the chapters and sections was adjusted;
- Testing standards, testing requirements and testing parameters of testing instrument and probe were specified;
- The quantity of reference blocks was reduced, and the requirements of reference blocks given in the former standard were kept;
- The test blocks for height of scanning surface dead zone and spread angle of sound beam were added;
- The use and operating requirements of simulating test block were adjusted;
- The requirements for calibration, checking, operation checking and inspection of testing equipments and apparatuses were added;
- The requirements for the technical level of TOFD testing were added, and suggestions on selection of testing methods for scanning surface dead zone, back wall dead zone and transverse flaw were provided;
- Safety requirements were added;
- The requirements of testing area were modified;
- Part of content in "selection of scanning mode" was adjusted;
- The determination method of dead zone height was added;

Nondestructive Testing of Pressure Equipments - Part 10: Ultrasonic Time of Flight Diffraction Technique

1 Scope

1.1 This Part of NB/T 47013 specifies the methods and quality classification requirements of ultrasonic time of flight diffraction technique (hereinafter referred to as "TOFD") adopted for pressure equipments.

1.2 This Part is applicable to such welded joints meeting the following conditions at the same time:

a) The material is low carbon steel or low alloy steel;

b) Butt joint of full-penetration structure type;

c) Nominal thickness of workpiece, t: 12mm≤t≤400mm (excluding weld reinforcement; when the base metal on both sides of weld is different, the nominal thickness of the thinner side shall be taken).

1.3 As for the stainless steel-steel clad plate, titanium-steel clad plate, aluminum-steel clad plate and nickel-steel clad plate used for such pressure equipments with the nominal thickness of base metal (of low carbon steel or low alloy steel) greater than or equal to 12mm, TOFD testing over the butt joint of base metal carried out from the side of base metal may refer to this Part; if TOFD testing over the butt joint of base metal is carried out from the side of cladding metal, it may also refer to this Part, but the area where ultrasonic sound beam may pass through shall be tested with normal probe according to the requirements of NB/T 47013.3 and it shall be free from any unbonding with flat bottom hole equivalent diameter greater than or equal to φ2mm.

1.4 As for the pressure equipments with the nominal thickness of base metal (of low carbon steel or low alloy steel) greater than or equal to 12mm and with clad layer of austenitic stainless steel, nickel alloy or other materials, the TOFD testing over the butt joint of base metal carried out from the side of base metal may refer to this Part.

1.5 As for the support members and structural members relevant to pressure equipments, the TOFD testing may refer to this Part; as for metallic materials with isotropic fine grain and low acoustic attenuation, the TOFD testing may also refer to this Part, but the change of acoustic characteristics shall be considered; as for the fillet joint of insertion type connection pipe, the TOFD testing may refer to this Part when the testing conditions required in this Part are met.

1.6 When the nominal thickness of base metal on both sides of welded joint is unequal, the testing may be carried out by making reference to Appendix A.

2 Normative References

The following documents for the application of this document are essential. Any dated reference, just dated edition applies to this document. For undated references, the latest edition (including any amendments) applies to this document.

GB/T 12604.1 Non-destructive Testing -Terminology - Terms Used in Ultrasonic Testing

GB/T 27664.1 Non-destructive Testing - Characterization and Verification of Ultrasonic Test Equipment - Part 1: Instruments

GB/T 27664.2 Non-destructive Testing - Characterization and Verification of Ultrasonic Test Equipment - Part 2: Probes

NB/T 47013.1 Nondestructive Testing of Pressure Equipments-Part 1: General Requirements

NB/T 47013.2 Nondestructive Testing of Pressure Equipments-Part 2: Radiographic Testing

NB/T 47013.3 Nondestructive Testing of Pressure Equipments- Part 3: Ultrasonic Testing

NB/T 47013.4 Nondestructive Testing of Pressure Equipments-Part 4: Magnetic Particle Testing

NB/T 47013.5 Nondestructive Testing of Pressure Equipments-Part 5: Penetrant Testing

NB/T 47013.6 Nondestructive Testing of Pressure Equipments-Part 6: Eddy Current Testing

JB/T 8428 Non-destructive Testing - General Specification for Ultrasonic Test Block

JB/T 9214 Non-destructive Testing - Test Methods for Evaluating Performance Characteristics of A-scan Pulse-echo Ultrasonic Testing Systems

JB/T 10062 Testing Methods for Performance of Probes Used in Ultrasonic Flaw Detection

3 Terminologies and Definitions

For the purpose of this Part, the terminologies and definitions defined in GB/T 12604.1 and NB/T 47013.1 as well as the following ones apply.

3.1

Coordinate definition

Define the meaning of the reference starting point O of testing and the meaning of coordinates X, Y and Z, see Figure 1.

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Flaw height

The maximum distance between flaw projections on the Z axis at a certain position in X axis direction, see *h* in Figure 8.

4 General Requirements

4.1 Testing personnel

4.1.1 Personnel engaged in TOFD testing shall meet the requirements of NB/T 47013.1.

4.1.2 The TOFD testing personnel shall be familiar with the adopted TOFD testing equipments and apparatuses.

4.1.3 The TOFD testing personnel shall possess actual testing experience and certain basic knowledge on the structure and manufacture of pressure equipments.

4.2 Testing equipments and apparatuses

4.2.1 Testing equipments

4.2.1.1 Testing equipments include instrument, probe, scanning device and accessories. Accessories are other articles required to realize the testing function of equipment; apparatuses include test block and couplant, etc.

4.2.1.2 Instrument and probe shall meet the requirements of their corresponding product standards and shall be accompanied with product quality certificate. The product quality certificate of instrument shall at least cover the warm-up time, low-voltage alarm or low-voltage automatic shutdown voltage, transmitted pulse repetition frequency, effective output impedance, transmitted pulse voltage, transmitted pulse width (with square-wave pulse as that of the transmitted pulse), frequency band of receiving circuit and other main performance parameters; the product quality certificate of probe shall at least cover center frequency, impedance or static capacitance, relative pulse echo sensitivity, relative frequency band width and other main performance parameters.

4.2.1.3 Requirements for testing instrument, probe and their combined performance

4.2.1.3.1 Testing instrument

4.2.1.3.1.1 The testing instrument shall at least have the functions of ultrasonic wave transmitting, receiving and amplifying as well as automatic data acquisition, recording, indication and analysis; its electrical performance and functions shall meet the requirements of Appendix B and relevant documentary evidence shall be provided; its electrical performance test method shall refer to the requirements of GB/T 27664.1.

4.2.1.3.1.2 Testing instrument may be classified into single-channel instrument and multi-channel instrument according to the quantity of ultrasonic wave transmitting and receiving channels.

4.2.1.3.2 Probe

4.2.1.3.2.1 Generally, two separated broadband narrow-pulse longitudinal-wave oblique-incidence probes are adopted and placed opposite to form a probe pair, with one for transmitting and the other receiving, and they are fixed on the scanning device; the performance indexes of probes shall meet the requirements of Appendix B and corresponding documentary evidence shall be provided, and the testing method may refer to GB/T 27664.2.

4.2.1.3.2.2 Under the promise of being able to prove having the required testing and measurement capability, other types of probes may also be used, like phased array probe, transverse wave probe or electromagnetic ultrasonic probe, etc.

4.2.1.3.3 Combined performance of testing instrument and probe

4.2.1.3.3.1 The combined performance of testing instrument and probe includes horizontal linearity, vertical linearity, surplus sensitivity, combination frequency, -12dB sound beam spread angle and signal noise ratio.

4.2.1.3.3.2 The combined performance of instrument and probe shall be determined in the following cases:

a) The newly-purchased TOFD instrument and (or) probe;
b) After repair or replacement of the main components of TOFD instrument and probe;
c) When the testing personnel have any suspicion.

4.2.1.3.3.3 The horizontal linearity shall be not larger than 1% and the vertical linearity shall be not larger than 5%.

4.2.1.3.3.4 The surplus sensitivity shall not be less than 42dB.

4.2.1.3.3.5 The deviation between the combination frequency of instrument and probe and the nominal frequency of probe shall not be larger than ±10%.

4.2.1.3.3.6 When the reference block specified in this Part is adopted, the diffracted signal amplitude of the reflector within the testing area shall be 50% of full screen by suitable testing setup and the signal noise ratio shall be above 8dB.

4.2.1.3.3.7 The testing methods of horizontal linearity, vertical linearity and surplus sensitivity shall meet the requirements of JB/T 9214, the testing method of combination frequency shall refer to the requirements of JB/T 10062, and the testing method of -12dB sound beam spread angle of the combination of instrument and probe is detailed in Appendix C.

4.2.1.4 Scanning device

4.2.1.4.1 Scanning device generally includes probe clamping part, driving part and guiding part, and also shall be installed with position sensor.

4.2.1.4.2 The probe clamping part shall be able to adjust and set the probe center separation (PCS), and shall ensure the relative position of flaw unchanged during scanning.

4.2.1.4.3 The guiding part shall be able to make the probe movement path be consistent with the proposed scanning line during scanning.

4.2.1.4.4 The driving part may adopt motor driving or manual driving.

4.2.1.4.5 The resolution and accuracy of position sensor shall meet the technological requirements of this Part.

4.2.2 Couplant

4.2.2.1 The medium which is effective and suitable for the tested workpiece shall be adopted as couplant.

4.2.2.2 The selected couplant shall ensure stable and reliable testing within the temperature range specified by the process specification.

4.2.3 Test block

4.2.3.1 Standard test block

Standard test block refers to the test block used for performance calibration of instrument and probe system. The standard test blocks adopted in this Part is CSK-IA and DB-PZ20-2

and they shall meet the corresponding requirements stated in NB/T 47013.3.

4.2.3.2 Reference block

4.2.3.2.1 Reference block refers to the test block used for testing calibration.

4.2.3.2.2 Reference block may adopt weldless plate, tube or forging, and may also adopt weldment; its acoustic performance shall be the same as or similar to that of workpieces, its boundary dimensions shall be able to represent the features of workpieces and also meet the scanning requirements of scanning device; the reflectors in reference block shall adopt machining mode; the reference blocks fabricated and processed according to the drawing in this Part shall meet the specified dimensional accuracy requirements and also shall be provided with corresponding documentary evidence.

4.2.3.2.3 When the area where ultrasonic sound beam may pass through in the material of reference block is tested with normal probe, it shall be free from such flaws with flat bottom hole equivalent diameter greater than or equal to φ2mm.

4.2.3.2.4 During the testing of longitudinal joint on curved surface workpiece, if the curvature radius of workpiece is greater than or equal to 150mm, plane reference block may be adopted; if the curvature radius of the tested surface is less than 150mm, the curved surface reference block with curvature radius of 0.9~1.5 times of that of workpiece shall be adopted, and the shape, size and quantity of reflectors in curved surface reference block shall be consistent with those of the plane reference block of the same thickness as the curved surface reference block.

4.2.3.2.5 Plane reference blocks adopted in this Part are as follows:

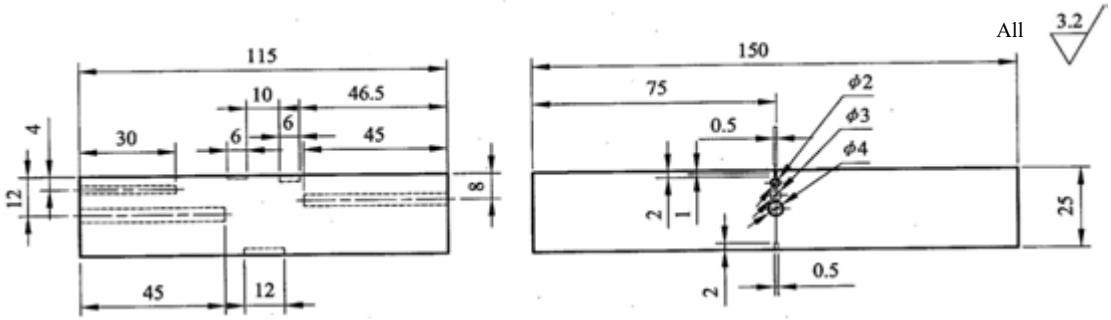
a) TOFD-A reference block: it is applicable to the testing of such workpieces with 12mm≤t≤25mm,see Figure 9;

b) TOFD-B reference block: it is applicable to the testing of such workpieces with 12mm≤t≤50mm,see Figure 10;

c) TOFD-C reference block: it is applicable to the testing of such workpieces with 12mm≤t≤100mm,see Figure 11;

d) TOFD-D reference block: it is applicable to the testing of such workpieces with 12mm≤t≤200mm,see Figure 12;

e) TOFD-E reference block: it is applicable to the testing of such workpieces with 12mm≤t≤400mm,see Figure 13.



Note: The aperture error shall not be larger than ±0.02mm, the verticality deviation of hole shall not be larger than ±0.1°, and other dimensional errors shall not be larger than ±0.05mm.

Figure 9 TOFD-A Reference Block

for the verification of testing process when the technical level of TOFD testing is C.

4.2.3.3.2 As for the simulating test block, its material shall be the same as or similar to the acoustic characteristics of tested workpiece, its boundary dimensions shall be able to represent the features of workpiece and shall meet the scanning requirements of scanning device, its thickness shall be 0.9~1.3 times of that of the workpiece and the maximum difference between them shall not be larger than 25mm.

4.2.3.3.3 The simulated flaws in simulating test block shall be prepared by welding procedure or shall adopt the actual flaws discovered in previous testing.

4.2.3.3.4 The simulated flaws in simulating test block shall meet the following requirements:

a) Position requirements: as for the simulating test block with wall thickness *t* less than or equal to 50mm, there shall be at least one simulated flaw on upper surface and lower surface as well as inside the test block; as for the simulating test block with wall thickness *t* larger than 50mm, it shall be ensured that there is at least one buried flaw in each thickness partition during the partition testing according to the requirements of 5.2.3; if the simulating test block is reversible, it is allowed to use one surface flaw to represent both the upper and lower surfaces.

b) Type requirements: the simulating test block shall at least contain one longitudinal flaw and one transverse flaw as well as one volume type flaw and one area type flaw respectively.

c) Dimensional requirements: the dimension of simulated flaw generally shall not be greater than the maximum allowable flaw dimension of the workpiece of the same thickness as specified in Grade II of Table 7.

d) If one simulating test block does not contain all the above-mentioned flaws, multiple simulating test blocks of the same scope may be adopted.

4.2.4 Requirements for calibration, checking, operation checking and inspection of testing equipments and apparatuses

4.2.4.1 Calibration, checking, operation checking and inspection shall be carried out on standard test block and reference block. During testing, the main sound beam of probe shall be perpendicular to the reflection plane of reflector so as to obtain maximum stable echoed signal.

4.2.4.2 Calibration or checking

4.2.4.2.1 Among the combined performance of testing instrument and probe, the horizontal linearity, vertical linearity, combination frequency and surplus sensitivity as well as attenuator accuracy of instrument shall be calibrated and recorded at least once every year, and the testing requirements shall meet the requirements of 4.2.1.3.3.

4.2.4.2.2 The surface corrosion and mechanical damage of standard test block and reference block shall be checked at least once every year according to the requirements of JB/T 8428.

4.2.4.3 Operation checking

4.2.4.3.1 Among the combined performance of instrument and probe, the horizontal linearity and vertical linearity shall undergo operation checking and also be recorded at least once every 6 months, and the testing requirements shall meet the requirements of 4.2.1.3.3.

4.2.4.3.2 When the reference block specified in this Part is adopted for testing under suitable testing setup, the equipment shall clearly display and measure the reflector inside,

prepared again or be revised.

Table 2 Relevant Factors Involved in the Testing Process Specification

No.	Relevant factors
1	Product scope (shape, specification, material, wall thickness, etc. of workpiece)
2	Applicable standards, laws and regulations
3	Testing equipments and apparatuses as well as the requirements of calibration, checking, operation checking or inspection
4	Testing process (probe configuration, scanning mode, thickness partition, etc.)
5	Pre-testing surface preparation requirements
6	Testing mode and process test report for dead zone
7	Testing mode and process test report for transverse flaw
8	Analysis and explanation of the testing data
9	Flaw evaluation and quality classification

4.4.3 The operating instructions shall be formulated according to the contents of process specification and the testing requirements of the tested workpiece, its contents not only shall meet the requirements of NB/T 47013.1, but also shall at least include:

a) The technical requirements of testing: executive standard, technical level of testing, acceptance level, testing time, testing ratio and pre-testing surface preparation requirements;

b) The testing equipments and apparatuses (including instrument, probe, scan device, couplant, name and specification/model of test block, items, time and performance indexes of performance checking);

c) The testing process parameters [including the selection of scanning surface, probe parameters and arrangement; settings of instrument, such as setting of sensitivity, scanning stepping, pulse repetition frequency, signal averaging, etc.; thickness partition and coverage of each partition; original height of scanning surface dead zone and the testing method for it; original height of back wall dead zone and the testing method for it; scanning mode; scanning speed; testing method (where necessary) for transverse flaw, etc.];

d) The requirements for testing identification;

e) The testing operation procedure and scanning sequence;

f) The specific requirements for testing record and data evaluation.

4.4.4 Process verification of operating instructions

4.4.4.1 Process verification shall be carried out for operating instructions before the first application.

4.4.4.2 When the technical level is Level A or B, verification may be carried out on reference block or actual workpiece.

4.4.4.3 When the technical level is Level C, simulating test block required in 4.2.3.3 shall also be selected for process verification. The specific mode and requirements of verification are as follows:

a) Corresponding simulating test block shall undergo TOFD testing according to operating instructions;

b) All simulated flaws in simulating test block shall be clearly displayed in TOFD image;

c) The size of measured simulated flaw shall be as close as possible to its actual size.

4.5 Testing procedure:

a) Formulating operating instructions according to process specification and the testing requirements of tested object;
b) Selecting and determining the testing process parameters;
c) Preparing the tested workpieces;
d) Performance checking of testing system;
e) Testing;
f) Rechecking the testing system;
g) Data evaluation;
h) Testing record;
i) Testing report.

4.6 Temperature

4.6.1 Testing shall be carried out within the specified temperature range; when conventional probe and couplant are used in testing, the surface temperature range of tested workpiece shall be controlled within 0℃~50℃; otherwise, special probe or couplant may be adopted.

4.6.2 Generally, effective measures shall be taken to avoid excessive high or low temperature. If it is inevitable, its influence on testing results shall be evaluated.

4.6.3 The temperature difference between the set &calibration temperature of testing system and the actual testing temperature shall be controlled within 20℃.

4.7 Safety requirements

4.7.1 The relevant requirements of 6.3 in NB/T 47013.1 shall be met.

4.7.2 Factors like possible electrical leakage shall be considered, and necessary protection measures shall be taken.

5 Selection and Setting of Testing Process Parameters

5.1 Determination of testing area

5.1.1 The testing area shall be represented by its height and width.

5.1.1.1 The height of testing area shall be the thickness of workpiece welded joint.

5.1.1.2 The width of testing area shall be the weld plus 10mm on each side of weld bond line.

5.1.2 For retesting of such parts with flaws already found or retesting of determined key parts, the testing area may be reduced to corresponding position.

5.2 Selection and setting of probe

5.2.1 Probe model and parameters shall be included in the probe selection. Generally, the longitudinal wave angle probe with wide angle shall be selected. For the two probes of one probe pair, their nominal frequency shall be the same, and their sound beam angle and crystal plate diameter should be the same too.

5.2.2 If the workpiece thickness t is less than or equal to 50mm, a probe pair may be adopted for testing, and it is recommended to so set the probe center separation that the sound beam intersection of this probe pair is at $2/3t$ of the depth.

5.2.3 If workpiece thickness t is larger than 50mm, the workpiece shall be divided into several different depth ranges in the thickness direction, and probe pairs with different

used for generally determining the flaw depth.

5.3.4 When original height of back wall dead zone under non-parallel scan is relatively large or the probe sound beam can't cover the testing area effectively, offset-parallel scan may be added in corresponding testing area.

5.3.5 When transverse flaws in welded joints need to be tested, oblique scan may be adopted.

5.3.6 Under the premise of satisfying the testing purpose, other applicable scanning modes may also be adopted according to different needs.

5.3.7 When multi original scanning modes are adopted, scanning sequence shall be arranged properly and noted in operating instructions.

5.4 Determination of original height of scanning surface dead zone and testing mode

5.4.1 Original height of scanning surface dead zone

5.4.1.1 Practical measurement method shall be adopted for the determination of original height of scanning surface dead zone.

5.4.1.2 The test block used for the original height of scanning surface dead zone as required in Figure 14 shall be adopted for measurement. After side holes in different depths are scanned respectively by the set scanning device, the corresponding depth of the upper edge of the detectable transverse hole in minimum depth is the original height of scanning surface dead zone.

5.4.2 Testing mode of scanning surface dead zone

5.4.2.1 The testing mode of scanning surface dead zone may be selected by making reference to 4.3.

5.4.2.2 If pulse-echo creeping wave method is adopted, the specification & model and arrangement mode of creeping wave probe shall be specified in process.

5.5 Determination of original height of back wall dead zone and testing mode

5.5.1 The original height of back wall dead zone shall be calculated according to Formula (1):

$$\Delta h = t\left(1-\sqrt{1-\frac{x^2}{s^2+t^2}}\right) \tag{1}$$

Where,

t-the workpiece thickness;

x-the distance deviating from weld center line (herein, it is half the width of back wall testing area);

s-a half of probe center separation.

5.5.2 Testing mode of back wall dead zone

5.5.2.1 The testing mode of back wall dead zone may be selected by making reference to 4.3.

5.5.2.2 If offset-parallel scan mode is adopted, the offset direction, offset amount and height of back wall dead zone after offsetting shall be specified in process [it may be calculated by making reference to Formula (1)].

5.6 Determination of testing mode for transverse flaws

5.6.1 The testing mode of transverse flaws may be selected by making reference to 4.3.

5.6.2 If oblique scan mode is adopted, the oblique scan angle, probe selection and setting and so on shall be specified in process, and oblique scan shall be carried out synchronously

0.5μs later than lateral wave reaches receiving probe;

e) Depth parameter input of testing equipment after being calibrated by reference block may be adopted.

5.11 Setting of testing sensitivity

5.11.1 Prior to testing, the sensitivity of testing channel shall be set.

5.11.2 If workpiece thickness is not greater than 50mm and single testing channel is adopted, sensitivity may be set directly on the tested workpiece or the reference block specified in 4.2.3.2. If sensitivity is set directly on the tested workpiece, lateral wave amplitude shall be generally set as 40%~80% of the height of full screen; if lateral wave is not available, back wall echo amplitude may be adjusted as 80% of the height of full screen and then increased by 20dB~32dB; but if both lateral wave and back wall echo are unavailable, the material grain noise may be set as 5%~10% of the height of full screen, which may be used as sensitivity.

5.11.3 When testing in partition in thickness direction, reference blocks specified in 4.2.3.2 shall be adopted to set testing sensitivity of each testing channel. The weakest diffracted signal amplitude generated by each reflector in A-scan time window of each testing channel shall be set as 40%~80% of the height of full screen, which may be used as sensitivity. (in the uppermost partition, lateral wave amplitude may also be set as 40%~80% of the height of full screen).

5.12 Confirmation of the overall setting of testing system

5.12.1 After the completion of the setting of all testing process parameters, if the setting is carried out directly on the tested workpiece, actual scanning shall be carried out at the same position of the tested workpiece and this testing data shall be stored in testing record.

5.12.2 After the completion of the setting of all testing process parameters, if the setting is carried out with reference block, actual scanning shall be carried out on reference block and this testing data shall be stored in testing record.

5.12.3 If testing process parameters are unsuitable, necessary adjustment shall be made.

6 Testing

6.1 Scanning surface preparation

6.1.1 Weld spatter, scrap iron, oil dirt and other impurities on scanning zone of probe shall be eliminated and generally, scanning zone of probe shall be polished. The surface of scanning zone of probe shall be flat and smooth so as to be convenient for probe to scan and its surface roughness value R_a shall not be less than 12.5μm.

6.1.2 When the weld reinforcement is required to be reserved, suitable grinding shall be carried out if there is undercut, relative large upheaval and hollowness on the weld surface, and smooth transition shall be carried out to avoid affecting the testing result evaluation; When the weld reinforcement is required to be removed, it shall be polished to be parallel to the neighboring base metal. Generally, reinforcement shall be removed as required when the scanning mode is parallel scan.

6.1.3 Prior to testing, the initial point and direction of scanning shall be marked on the workpiece surface, and the reference line for the movement of scanning device may be drawn on the base metal at the position with a specified distance from the weld center line.

6.2 Base metal testing

6.2.1 If there is suspicion on the important workpiece or testing personnel, according to the relevant regulations in NB/T 47013.3, testing shall be carried out on the base metal zone with ultrasonic wave sound beam passing through by virtue of normal probe or in the process of TOFD testing.

6.2.2 The reflector affecting testing result in base metal shall be recorded.

6.3 Couplant

The couplant adopted in testing shall be identical to the couplant adopted in setting and calibration of testing system.

6.4 Process parameter adjustment before testing

6.4.1 Sensitivity shall be checked before actual scanning if sensitivity setting is directly carried out on tested workpiece; if reference block is adopted in sensitivity setting, surface coupling compensation shall be carried out before workpieces are actually tested, the determination of surface coupling compensation amount may refer to relevant content of NB/T 47013.3.

6.4.2 If reference block is adopted in the setting of A-scan time window and depth calibration, depth indication in actual workpiece shall be checked, ensure that depth indication deviation is not greater than 3% of workpiece thickness or 2mm (take the larger value), otherwise necessary adjustment shall be carried out.

6.4.3 For the longitudinal welded joint of curved surface or other non-planar workpieces, necessary adjustment shall be carried out to depth indication.

6.5 Scanning

6.5.1 While scanning, it shall be ensured that the deviation between actual scanning route and the proposed scanning route is not greater than 10% of the probe center separation.

6.5.2 While scanning, it shall be ensured that the scanning speed is less than or equal to the maximum scanning speed v_{max}, and the coupling effect and the required data collecting shall also be ensured.

The maximum scanning speed shall be calculated according to Formula (2):

$$v_{max} = \frac{PRF}{N} \Delta x \tag{2}$$

Where,

v_{max} - the maximum scanning speed, mm/s;

PRF - the pulse repetition frequency for inspiring probe, Hz;

Δx - the set scanning stepping value, mm;

N - the set signal averaging treatment frequency.

6.5.3 For each scanning, the scanning length shall not exceed 2,000mm; if the scanning is required to be carried out by sections in the length direction of weld, the overlapped coverage of each scanning section shall be 20mm at least; as for circumferential weld, the stop position of scanning shall be at least 20mm away from its starting position.

6.5.4 The wave amplitude shall be watched out closely during scanning. When the amplitude of lateral wave, back wall echo, material grain noise or waveform converted wave is reduced more than 12dB or when it is suspected that the coupling is poor, this entire section shall be scanned again; when the screen is full of lateral wave or grain noise amplitude

7.2 Relevant indications and non-relevant indications

7.2.1 Relevant indications

7.2.1.1 Relevant indications are classified into indication of surface opening type and buried flaw type.

7.2.1.2 Surface opening flaw indication

7.2.1.2.1 Surface opening flaw indication may be subdivided into the following three categories:

a) Scanning surface opening type: The indication of this type is usually the weakening, disappearance or deformation of lateral wave, and the diffracted signal generated only by one endpoint (lower endpoint of flaw) may be observed and it has the same phase as the lateral wave;

b) Back wall opening type: The indication of this type is usually the weakening, disappearance, delay or deformation of back wall echo, and the diffracted signal generated only by one endpoint (lower endpoint of flaw) may be observed and it has the opposite phase to the lateral wave;

c) Penetration type: The indication of this type is the simultaneous weakening or disappearance of lateral wave and back wall echo, and diffracted signals may be generated in many places along the wall thickness direction.

7.2.1.2.2 While doing data analysis, attention to the phase of flaw signal which is the nearest to lateral wave and back wall echo shall be paid. The preliminary judgment of whether the flaw upper and lower endpoint is hidden in the surface dead zone or on the workpiece surface shall be made.

7.2.1.3 Buried flaw indication

7.2.1.3.1 Buried flaw indication may be subdivided into the following three categories:

a) Dotted indication: The indication of this type is in hyperbolic arc shape, and coincides with fit arc cursor, and with no measurable length and height.

b) Linear indication: The indication of this type is spindly, and with no measurable height;

c) Strip indication: The indication of this type is in strip shape, and diffracted signal generated from upper and lower endpoint is visible.

7.2.1.3.2 Generally, buried flaw indication has no influence on the signal of lateral wave or that of back wall echo.

7.2.2 Non-relevant indications

Indications caused by the overall structure or materials metallurgy, etc. of workpiece other than flaws.

7.2.3 Recording and measurement of relevant indications and non-relevant indications

a) As for surface opening flaw indications and buried linear and strip flaw indications, at least flaw position, flaw length, flaw depth and flaw height shall be measured, when necessary, the position flaw deviating from weld center line shall also be measured;

b) As for buried type dotted indications, they shall be recorded when there are relatively many of them in certain area;

c) As for non-relevant indications, their positions shall be recorded.

7.2.4 When necessary, in order to obtain more information, additional parallel scan for

relevant found indications may be added.

7.2.5 Typical TOFD images

Typical TOFD images are detailed in Appendix E.

7.3 Determination of flaw position and flaw length

7.3.1 Flaw position

7.3.1.1 The position of flaw on X axis shall be determined according to the TOFD image obtained by non-parallel scan or offset-scan.

7.3.1.2 Generally, fit arc cursor method is adopted to determine front/rear endpoint position of flaw along X axis:

a) As for dotted indication, the position value in weld direction when fitting arc cursor and relevant indication coincide may be adopted;

b) As for other indications, their front/rear endpoint position shall be determined respectively. Values in X axis where fit arc cursor and relevant indication coincide may be adopted.

7.3.1.3 Focus probe may be adopted to improve the determination precision of flaw position.

7.3.2 Flaw length shall be calculated according to front/rear endpoint position of flaw in X axis, see *l* in Figure 8 and Figure 16.

7.4 Determination of flaw depth

7.4.1 Surface opening flaw indications:

a) Scanning surface opening type and penetration type: flaw depth is 0;

b) Back wall opening type: the distance between flaw upper endpoint and scanning surface is the flaw depth.

7.4.2 Buried flaw indication:

a) Dotted indication: Values in X axis where fit arc cursor and dotted indication coincide may be adopted;

b) Linear indication and strip indication: the distance between its upper endpoint and scanning surface is the flaw depth.

7.4.3 In the TOFD indication by parallel scan, the reflected depth between flaw and upper endpoint nearest to scanning surface is the exact value of flaw depth.

7.5 Determination of flaw height

7.5.1 As for surface opening flaw indications: the flaw height is the maximum distance between the surface and upper (or lower) endpoint of the flaw. See *h* in Figure 16. If it is penetration type, the flaw height is the workpiece thickness.

7.5.2 As for buried type strip flaw indications, the flaw height is *h* as shown in Figure 8.

8.6 If quality grades evaluated for all kinds of flaws are different, the lowest quality grade shall be regarded as the quality grade for welded joints.

9 Testing Record and Report

9.1 The relevant information and data of the testing process shall be recorded in detail in accordance with the actual situation of operation on site. Apart from in line with the requirements of NB/T 47013.1, the testing record shall at least include the following content:

a) Content concerned with the tested workpiece: Name, No., specification, material, groove type, welding method, heat treatment condition, testing position and pre-testing surface condition, etc.;
b) Testing equipments and apparatuses: The instrument model and No., the probe model and No., scanning device, test block and couplant, etc.;
c) Parameters of testing process: Testing standard, technical level, No. of testing process and operating instructions, testing surface, testing area, probe layout drawing, testing system setting and the checked value, scanning mode, and temperature;
d) Schematic diagram for testing;
e) Testing data and analysis: The name and analysis result of each data file, (including flaw position, size and quality grade that need recording and measuring);
f) The set and confirmed overall data of testing system; the data and result verified by simulating test block shall also be included when the technical level is Level C.

9.2 Testing report shall be issued according to the testing record. Apart from in line with NB/T 47013.1, the testing report shall at least include the following content:

a) Entrusting party;
b) Content concerned with tested workpiece: The type of pressure equipment, the name, No., specification and size, material, groove type, welding method, heat treatment condition, testing position and testing ratio, surface condition during testing, testing time and temperature of the tested workpiece, etc.;
c) Testing equipments and apparatuses: Specification/model of instrument and probe, scanning device, couplant, test block (where necessary), etc.;
d) Parameters of testing process: No. of test operating instructions, testing surface, probe setting and scanning mode;
e) Testing results and conclusion: Name of data file, the position and size of recordable flaw, quality grade, name of data file and testing conclusion.

Appendix B

(Normative)

Requirements for Performance Indexes of TOFD Testing Instrument and Probe

B.1 Requirements for performance indexes of testing instrument (see Table B.1)

Table B.1 Requirements for Performance Indexes of TOFD Testing Instrument

No.	Item		Technical requirements
1	Requirements for electric performance	(1) Transmitting performance parameter	① The inspired electric pulse may be unipolar or bipolar and it shall be square wave
			② The rise time of transmitted pulse in each channel of instrument (the rise time from pulse front edge to 10% ~ 90% of pulse peak) shall be less than 25ns
			③ The voltage amplitude of transmitted pulse in each channel of instrument shall be adjustable, and the maximum value shall not be less than 200V (if is not reached under special circumstances, it at least shall not be less than 100V and certification documents which certify that the instrument is with corresponding testing capacity shall be provided), the deviation between the measured value and set value (with load 50Ω) of transmitted pulse voltage shall not be greater than 20% of set value
			④ The width scope of transmitted pulse in each channel of instrument shall at least include 50ns~500ns and shall be adjustable, the stepping value shall be less than or equal to 10ns, the deviation between the measured value and the set value of transmitted pulse shall not be greater than 10% of set value
			⑤ The transmitted pulse repetition frequency of each channel of instrument shall be adjustable, and the maximum value shall be able to reach 500Hz and above, the deviation between the measured value and set value of transmitted pulse repetition frequency shall not be greater than 10% of set value
		(2) Receiving performance	① Measured according to -3dB, the frequency band range of receiving and amplifying circuit shall at least include 0.6MHz~15MHz
			② Digital sampling frequency shall be at least 60MHz
			③ Measured net gain of instrument shall not be less than 75dB
		(3) Other electrical performance shall meet the requirements of Appendix A in "Nondestructive Testing of Pressure Equipments- Part 3: Ultrasonic Testing" (NB/T 47013.3)	
2	Functional requirements	(1) Indication function	① The testing indication by each channel of instrument shall at least include A-scan signal and TOFD image, and A-scan signal shall use RF waveform
			② The A-scan signal indicated and recorded by each channel of the instrument shall be free from visible distortion or deformation
			③ The instrument shall at least be able to indicate the TOFD image in at least 256 grey level or chromaticity
			④ The instrument software shall at least be provided with necessary analysis functions like synchronous display of the TOFD image and corresponding A-scan signal as well as fitting curve cursor, lateral wave removal and amplification of partial position signal, etc.