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Badania ultradźwiękowe

Zastosowanie techniki czasu przejścia wiązki dyfrakcyjnej (TOFD)

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Essais non destructifs des assemblages soudés - Contrôle par ultrasons - Utilisation de la technique de diffraction des temps de vol (TOFD) (ISO 10863:2020)

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European foreword

This document (EN ISO 10863:2020) has been prepared by Technical Committee ISO/TC 44 "Welding and allied processes" in collaboration with Technical Committee CEN/TC 121 “Welding and allied processes” the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2020, and conflicting national standards shall be withdrawn at the latest by December 2020.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

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Endorsement notice

The text of ISO 10863:2020 has been approved by CEN as EN ISO 10863:2020 without any modification.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 5, *Testing and inspection of welds.*

This second edition cancels and replaces the first edition (ISO 10863:2011), which has been technically revised.

The main changes compared to the previous edition are as follows:

— the whole document has been updated to the state of the art; ISO 22232 series has been taken into account;

— Clause 3 has been updated;

— Figure 1 to Figure 6 have been added;

— Figure B.1 to Figure B.18 have been updated.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Official interpretations of ISO/TC 44 documents, where they exist, are available from this page: https://committee.iso.org/sites/tc44/home/interpretation.html.

Non-destructive testing of welds — Ultrasonic testing — Use of time-of-flight diffraction technique (TOFD)

1 Scope

This document specifies the application of the time-of-flight diffraction (TOFD) technique to the semi- or fully automated ultrasonic testing of fusion-welded joints in metallic materials of minimum thickness 6 mm.

It applies to full penetration welded joints of simple geometry in plates, pipes, and vessels, where both the weld and the parent material are low-alloyed carbon steel. Where specified and appropriate, TOFD can also be used on other types of materials that exhibit low ultrasonic attenuation (especially that due to scatter).

Where material-dependent ultrasonic parameters are specified in this document, they are based on steels having a sound velocity of (5 920 ± 50) m/s for longitudinal waves and (3 255 ± 30) m/s for transverse waves. It is necessary to take this fact into account when testing materials with a different velocity.

This document makes reference to ISO 16828 and provides guidance on the specific capabilities and limitations of TOFD for the detection, location, sizing and characterization of discontinuities in fusion-welded joints. TOFD can be used as a stand-alone method or in combination with other non-destructive testing (NDT) methods or techniques, for manufacturing inspection, and for in-service inspection.

This document specifies four testing levels (A, B, C, D) in accordance with ISO 17635 and corresponding to an increasing level of testing reliability. Guidance on the selection of testing levels is provided.

This document permits assessment of TOFD indications for acceptance purposes. This assessment is based on the evaluation of transmitted, reflected and diffracted ultrasonic signals within a generated TOFD image.

This document does not include acceptance levels for discontinuities.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5577, *Non-destructive testing — Ultrasonic testing — Vocabulary*

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

ISO 16828, *Non-destructive testing — Ultrasonic testing — Time-of-flight diffraction technique as a method for detection and sizing of discontinuities*

ISO 17640, *Non-destructive testing of welds — Ultrasonic testing — Techniques, testing levels, and assessment*

ISO 22232-1[1)], *Non-destructive testing — Characterization and verification of ultrasonic test equipment — Part 1: Instruments*

1) Under preparation. (Preparation at the time of publication: ISO/FDIS 22232-1.)

ISO 22232-2[2)], *Non-destructive testing — Characterization and verification of ultrasonic test equipment — Part 2: Probes*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5577 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
time-of-flight diffraction image
TOFD image
two-dimensional image, constructed by collecting adjacent A-scans while moving the *time-of-flight diffraction setup* (3.3)

Note 1 to entry: The signal amplitude of the A-scans is typically represented by grey-scale values.

3.2
time-of-flight diffraction indication
TOFD indication
pattern or disturbance in the *time-of-flight diffraction image* (3.1) which can need further evaluation

3.3
time-of-flight diffraction setup
TOFD setup
probe arrangement defined by probe characteristics (e.g. frequency, probe element size, beam angle, wave mode) and *probe centre separation* (3.6)

3.4
beam intersection point
point of intersection of the two main beam axes

3.5
lateral wave
longitudinal wave traveling the shortest path from transmitter probe to receiver probe

3.6
probe centre separation
PCS
distance between the index points of the two probes

Note 1 to entry: The PCS for two probes located on a curved surface is the straight-line, geometric separation between the two probe index points and not the distance measured along the surface.

3.7
offset scan
scan parallel to the weld axis, where the *beam intersection point* (3.4) is not on the centreline of the weld

4 General remarks on the capabilities of the technique

General principles of the TOFD technique are described in ISO 16828. For the testing of fusion-welded joints, some specific capabilities and limitations of the technique shall be considered.

2) Under preparation. (Preparation at the time of publication: ISO/DIS 22232-2.)

The TOFD technique is an ultrasonic image-generating technique, which offers the capability of detection, location, and sizing. To a certain extent, characterization of discontinuities in the weld material as well as in the adjacent parent material is also possible.

Compared with purely reflection-based techniques, the TOFD technique, which is based on diffraction as well as reflection, is less sensitive to the orientation of the discontinuity. Discontinuities oriented perpendicular to the surface, and at intermediate angles of tilt, are detectable as well as discontinuities in the weld fusion faces.

In certain circumstances (e.g. thickness, weld preparation, scope of testing) more than one single TOFD setup is required.

A typical TOFD image is linear in time (vertical axis) and probe movement (horizontal axis). Because of the V-configuration of the ultrasound paths, the location of a possible discontinuity is then non-linear. TOFD testing shall be carried out in a correct and consistent way, such that valid images are generated which can be evaluated correctly, e.g. coupling losses and data acquisition errors shall be avoided, see 12.2.

The interpretation of TOFD images requires skilled and experienced operators. Some typical TOFD images of discontinuities in fusion-welded joints are provided in Annex B.

There is a reduced capability for the detection of discontinuities close to or connected with the scanning surface or with the opposite surface. This shall be considered especially for crack-sensitive steels or at in-service inspections. In cases where full coverage of these zones is required, additional measures shall be taken, e.g. TOFD can be accompanied by other NDT methods or techniques.

Diffracted signals from weld discontinuities can have small amplitude responses. The grain scatter effect from coarse-grained material can hinder the detection and evaluation of such responses. This shall be taken into account whenever testing such material.

5 Testing levels

This document specifies four testing levels (A, B, C and D, see Table 1). From testing level A to testing level C an increasing reliability is achieved.

Table 1 — Testing levels

Testing level	TOFD setup	Reference block for setup verification (see 8.2)	Reference block for sensitivity settings (see 10.1.4)	Offset scan	Written test procedure
A	As in Table 2	No	No	No	This document
B	As in Table 2	No	Yes	No	This document
C	As in Table 2	Yes	Yes	a	Yes
D	As defined by specification	Yes	Yes	a	Yes

a The necessity, number and position of offset scans shall be determined.

If the specified acceptance level requires detection of a certain discontinuity size at both surfaces or one surface of the weld (see Clause 4), this can necessitate the use of techniques or methods outside the scope of this document.

For manufacturing inspections (see also ISO 17635), all testing levels are applicable. Level A is only applicable for wall thicknesses up to 50 mm. For in-service inspections, only testing level D shall be applied.

6 Information required prior to testing

6.1 Items to be defined by specification

Information on the following items is required:

a) purpose and extent of TOFD testing (see Clause 5 and Clause 8);

b) testing levels (see Clause 5), e.g.:

1) whether a written test procedure is required,

2) whether reference blocks are required;

c) specification of reference blocks, if required (see 10.3);

d) manufacturing or operation stage at which the testing is to be carried out;

e) requirements for: temperature, access and surface conditions (see Clause 8);

f) reporting requirements (see Clause 13);

g) acceptance criteria;

h) personnel qualifications (see 7.1).

6.2 Specific information required by the operator before testing

Before any testing of a welded joint can begin, the operator shall have access to all the information as specified in 6.1 together with the following additional information:

a) written test instruction or procedure (see 6.3), if required;

b) type(s) of parent material and product form (i.e. cast, forged, rolled);

c) joint preparation and dimensions;

d) welding procedure or relevant information on the welding process;

e) time of testing relative to any post-weld heat treatment;

f) result of any parent metal testing carried out prior to and/or after welding;

g) discontinuity type and morphology to be detected.

6.3 Written test instruction or procedure

For testing levels A and B, this document satisfies the need for a written test procedure.

For testing levels C and D, or where the techniques described in this document are not applicable to the welded joint to be tested, a specific written test procedure shall be used.

When data collection is performed by personnel qualified to Level 1 according to ISO 9712, a written test instruction shall be prepared. The written test instruction shall contain as a minimum the information listed in Clause 13.

7 Requirements for test personnel and test equipment

7.1 Personnel qualifications

In addition to a general knowledge of ultrasonic weld testing, all personnel shall be competent in the TOFD technique. Documented evidence of their competence (level of training and experience) is required.

Preparation of written test instructions, final off-line analysis of data, and acceptance of the report shall be performed by personnel qualified as a minimum to Level 2 in accordance with ISO 9712 or equivalent in ultrasonic testing in the relevant industrial sector. In accordance with a written instruction and under the supervision of Level 2 or Level 3 personnel, equipment setup, data acquisition, data storage, and report preparation can be performed by personnel qualified to a minimum of Level 1 in accordance with ISO 9712 or equivalent in ultrasonic testing in the relevant industrial sector.

For data acquisition, the Level 1 personnel may be supported by an assistant technician.

In cases where the above minimum qualifications are not considered adequate, job-specific training shall be carried out.

7.2 Test equipment

7.2.1 Ultrasonic instrument

The ultrasonic instrument used for the TOFD technique shall comply with the requirements of ISO 22232-1, where applicable.

The TOFD software shall not mask any problems such as loss of coupling, missing scan lines, synchronization errors or electronic noise.

In addition, the requirements of ISO 16828 shall apply, taking into account the following:

a) the instrument shall be able to select an appropriate portion of the time base within which A-scans are digitized;

b) it is recommended that a sampling rate of the A-scan of at least 6 times the nominal probe frequency be used.

7.2.2 Ultrasonic probes

Probes used for the TOFD technique on welds shall comply with ISO 22232-2 and ISO 16828.

Adaptation of probes to curved scanning surfaces shall comply with ISO 17640.

A recommendation for the selection of probes is given in Table 2.

7.2.3 Scanning mechanisms

The requirements of ISO 16828 shall apply. To achieve consistency of the images (collected data), guiding mechanisms may be used.

8 Preparation for testing

8.1 Volume to be tested

Testing shall be performed in accordance with ISO 16828. The purpose of the testing shall be defined by specification. Based on this, the volume to be tested shall be determined.

The volume to be tested is located between the probes. For testing levels A and B, the probes shall be placed symmetrically about the weld centreline. For testing levels C and D, additional offset scans may be required.

For manufacturing inspection, the volume to be tested is defined as the zone which includes weld and parent material for at least 10 mm on each side of the weld or the width of the heat-affected zone, whichever is greater. In all cases, the whole volume to be tested shall be covered.

Normally these tests are performed in accordance with recognized standards applying acceptance levels for quality assurance. If fitness-for-purpose methods are applied, then corresponding acceptance criteria shall be specified.

For in-service inspections, the volume to be tested may be targeted to specific areas of interest, e.g. the inner third of the weld body. The acceptance criteria and minimum discontinuity size to be detected in the area of interest shall be specified.

8.2 Setup of probes

The probes shall be set up to ensure adequate coverage and optimum conditions for the initiation and detection of diffracted signals in the area of interest. For butt welds of simple geometry and with narrow weld crowns at the opposite surface, the testing shall be performed in one or more setups (scans) dependent on the wall thickness (see Table 2). For other configurations, e.g. X-shaped welds, different base metal thickness at either side of the weld, or tapering, Table 2 may be used as guidance. In this case, the effectiveness and coverage of the setup shall be verified by using reference blocks. Selection of probes for full coverage of the complete weld thickness should follow Table 2. Care should be taken to choose appropriate combinations of parameters. For example, in the thickness range 15 mm to 35 mm a frequency of 10 MHz, a beam angle of 70° and a transducer size of 3 mm can be appropriate for a thickness of 16 mm, but not for 32 mm thickness.

For testing levels A and B, it is recommended that the TOFD setup be verified by the use of reference blocks.

For testing levels C and D, all the setups chosen for the test object shall be verified by use of reference blocks.

If setup parameters are not in accordance with Table 2, the capability shall be verified by using reference blocks.

For in-service inspection the intersection point of the beam centrelines should be optimized for the specified volume to be tested.

Table 2 — Recommended TOFD setups for simple butt welds dependent on wall thickness

Thickness *t* mm	Number of TOFD setups	Depth range Δ*t* mm	Centre frequency *f* MHz	Beam angle (longitudinal waves) *α* °	Transducer size mm	Beam intersection
6 to 10	1	0 to *t*	15	70	2 to 3	2/3 of *t*
>10 to 15	1	0 to *t*	15 to 10	70	2 to 3	2/3 of *t*
>15 to 35	1	0 to *t*	10 to 5	70 to 60	2 to 6	2/3 of *t*
>35 to 50	1	0 to *t*	5 to 3	70 to 60	3 to 6	2/3 of *t*
>50 to 100	2	0 to *t*/2	5 to 3	70 to 60	3 to 6	2/6 of *t*
		t/2 to *t*	5 to 3	60 to 45	6 to 12	5/6 of *t*
>100 to 200	3	0 to *t*/3	5 to 3	70 to 60	3 to 6	2/9 of *t*
		t/3 to 2*t*/3	5 to 3	60 to 45	6 to 12	5/9 of *t*
		2*t*/3 to *t*	5 to 2	60 to 45	6 to 20	8/9 of *t*
>200 to 300	4	0 to *t*/4	5 to 3	70 to 60	3 to 6	2/12 of *t*
		t/4 to *t*/2	5 to 3	60 to 45	6 to 12	5/12 of *t*
		t/2 to 3*t*/4	5 to 2	60 to 45	6 to 20	8/12 of *t*
		3*t*/4 to *t*	3 to 1	50 to 40	10 to 20	11/12 of *t*; or *t* for $\alpha \leq 45°$

8.3 Scan increment setting

The scan increment setting shall be dependent on the wall thickness to be tested. For thicknesses up to 10 mm, the scan increment shall be no more than 0,5 mm. For thicknesses between 10 mm and 150 mm, the scan increment shall be no more than 1 mm. Above 150 mm, the scan increment shall be no more than 2 mm.

8.4 Geometry considerations

Care should be taken when testing welds of complex geometry, e.g. welds joining materials of unequal thickness, materials that are joined at an angle, or nozzles. As TOFD is based on the measurement of time intervals of sound waves taking the shortest path between the point of emission and the point of reception via points of reflection or diffraction, some areas of interest can be obscured. Additional scans can overcome this problem in many cases.

Planning testing of complex geometries requires in-depth knowledge of sound propagation, representative reference blocks and sophisticated software and is beyond the scope of this document.

8.5 Preparation of scanning surfaces

Scanning surfaces shall be wide enough to permit full coverage of the volume to be tested.

Scanning surfaces shall be even and free from foreign matter likely to interfere with probe coupling (e.g. rust, loose scale, weld spatter, notches, grooves). Waviness of the test surface shall not result in a gap between one of the probes and test surface greater than 0,5 mm. These requirements shall be ensured by dressing, if necessary.

Scanning surfaces may be assumed to be satisfactory if the surface roughness, *Ra*, is not greater than 6,3 µm for machined surfaces, or not greater than 12,5 µm for shotblasted surfaces.

8.6 Temperature

When using conventional probes and couplants, the surface temperature of the test object shall be in the range 0 °C to 50 °C.

For temperatures outside this range, the suitability of the equipment shall be verified.

8.7 Couplant

In order to generate proper images, a couplant shall be used which provides a constant transmission of ultrasound between the probes and the test object.

The couplant used for calibration shall be the same as that used in subsequent testing and post-calibrations.

8.8 Provision of datum points

In order to ensure repeatability of the testing, a permanent reference system shall be applied.

9 Testing of base material

The base material does not generally require prior testing for laminations (typically by using straight-beam probes), as they are detected during the TOFD weld testing. Nevertheless, the presence of discontinuities in the base material adjacent to the weld can lead to obscured areas or to difficulties in interpretation of the data.

10 Range and sensitivity settings

10.1 Settings

10.1.1 General

Setting of range and sensitivity in accordance with this document and ISO 16828 shall be carried out prior to each testing. Any change of the TOFD setup, e.g. probe centre separation (PCS), requires a new setting.

Noise should be minimized, e.g. by signal averaging.

10.1.2 Time window

The time window shall at least cover the depth range as shown in Table 2:

a) for full-thickness testing using only one setup, the time window recorded should start at least 1 µs prior to the time of arrival of the lateral wave, and should extend beyond the first mode-converted back-wall signal, where possible;

b) if more than one setup is used, the time windows shall overlap by at least 10 % of the depth range.

The start and extent of the time windows shall be verified on the test object.

10.1.3 Time-to-depth conversion

For a given PCS, setting of time-to-depth conversion is best carried out using the lateral wave signal and the back-wall signal with the known material velocity.

This setting shall be verified (for all testing levels) by a suitable block of known thickness (accuracy 0,05 mm). At least one depth measurement shall be performed in the depth range of interest, typically by recording a minimum of 20 A-scans.

The measured thickness or depth shall be within 0,2 mm of the actual or known thickness or depth. For curved components geometrical corrections can be necessary.

10.1.4 Sensitivity settings

For all testing levels, the sensitivity shall be set on the test object. The amplitude of the lateral wave shall be between 40 % and 80 % of full screen height (FSH). In cases where the use of the lateral wave is not appropriate (e.g. because of surface conditions, use of steep beam angles), the sensitivity shall be set such that the amplitude of the back-wall signal is between 18 dB and 30 dB above FSH. When the use of neither a lateral wave nor a back-wall signal is appropriate, sensitivity should be set such that the material grain noise is between 5 % and 10 % of FSH.

For testing levels B, C, and D, it shall be verified by the use of the test block(s) that the sensitivity is sufficient to detect real discontinuities in the respective depth zone or, if not available, machined discontinuities (e.g. notches, side-drilled holes), see 10.3.

10.2 Checking of the settings

Checks to confirm the range and sensitivity settings shall be performed at least every 4 h and on completion of the testing. Checks shall also be carried out whenever a system parameter is changed or changes in the equivalent settings are suspected. If a reference block was used for the initial setup, the same reference block should be used for subsequent checks. Alternatively, a smaller block with known transfer properties may be used, provided that this is cross-referenced to the initial reference block.

Where a reference block was not used, but instead the test object was used for checking, then subsequent checks shall be carried out at the same location as the initial check.

If deviations from the initial settings, in accordance with 10.1.3 and 10.1.4, are found during these checks, the corrections given in Table 3 shall be carried out.

Table 3 — Sensitivity and range corrections

Sensitivity	
Deviations ≤6 dB	No action required; data may be corrected by software
Deviations >6 dB	Settings shall be corrected and all tests carried out since the last valid check shall be repeated
Range	
Deviations ≤0,5 mm or 2 % of depth range, whichever is greater	No action required
Deviations >0,5 mm or 2 % of depth range, whichever is greater	Settings shall be corrected and all tests carried out since the last valid check shall be repeated

10.3 Reference blocks

10.3.1 General

Depending on the testing level, a reference block shall be used to determine the adequacy of the testing (e.g. coverage, sensitivity setting). Recommendations for reference blocks are given in Annex A.

10.3.2 Material

The reference block should be made of similar material to the test object (e.g. with regard to sound velocity, grain structure and surface condition).

10.3.3 Dimensions and shape

The thickness of the reference block should be representative of the thickness of the test object. Therefore, the thickness should be limited to a minimum and a maximum value related to the thickness of the test object.

Thickness of reference blocks is recommended to be between 0,8 times and 1,5 times the thickness of the test object with a maximum difference in thickness of 20 mm compared to the test object. Care should be taken that on the centreline between the probes there is no angle smaller than 40° at the bottom of the reference block (see Figure A.1). The minimum thickness of the reference block should be chosen such that the beam intersection point of the chosen setup is always within the reference block (see Figure A.2).

The length and width of the reference block should be chosen so that all the artificial discontinuities within the area of interest can be captured within the appropriate scan range.

For testing of longitudinal welds in cylindrical test objects, curved reference blocks shall be used having diameters from 0,9 times to 1,5 times the diameter of the test object. For objects having a diameter ≥300 mm, a flat reference block may be used.

10.3.4 Reference reflectors

For thicknesses between 6 mm and 25 mm, at least three reflectors are required. For thicknesses >25 mm, at least five reflectors are required. Typical reference reflectors used are side-drilled holes and notches. Different shapes of notches may be used provided they generate diffracted signals.

11 Weld testing

The two probes are scanned parallel to the weld at a fixed distance and orientation in relation to the weld centreline.

Data collected during a scan can be used for detection and sizing purposes. Further evaluation of TOFD indications as detected during the initial scanning may require additional scans such as offset scans, scans perpendicular to the discontinuity or complementary TOFD setups.

Scanning speed shall be chosen such that satisfactory images are generated (see 12.2). The scanning speed is dependent on scan increment, signal averaging, pulse repetition frequency, data acquisition frequency, and the volume to be tested. Missing scan lines can indicate that too high a scanning speed has been used. A maximum of 5 % of the total number of lines collected in one single scan may be missed, but no adjacent lines shall be missed.

If a weld is scanned in more than one part, an overlap of at least 20 mm between the adjacent scans is required. When scanning circumferential welds, the same overlap is required for the end of the last scan with the start of the first scan.

Reduction of signal amplitude of lateral wave, back-wall signal, grain noise, or mode-converted signals during a scan by more than 12 dB can indicate loss of coupling (see Figures B.7 and B.8). If coupling loss is suspected, the area shall be re-scanned. If the results are still not satisfactory, appropriate action shall be taken.

Saturation of the lateral wave or excessive grain noise (>20 % of FSH) during scanning requires corrective action and re-scanning.

12 Interpretation and analysis of TOFD images

12.1 General

Interpretation and analysis of TOFD images are generally performed by:

a) assessing the quality of the TOFD image;

b) identification of relevant TOFD indications and discrimination of non-relevant TOFD indications;

c) classification of relevant TOFD indications in terms of:

   1) embedded (linear, point-like),

   2) surface breaking;

d) determination of location (typically position in *x*-direction and *z*-direction) and size (length and through-wall extent);

e) evaluation against acceptance criteria.

12.2 Assessing the quality of the TOFD image

A TOFD test shall be carried out such that satisfactory images are generated which can be evaluated with confidence. Satisfactory images are defined by appropriate:

a) coupling, see 8.7 and Clause 11;

b) data acquisition, see Clause 11;

c) sensitivity setting, see 10.1.4;

d) time-base setting, see 10.1.2.

Assessing the quality of TOFD images requires skilled and experienced operators (see 7.1). The operator shall decide whether unsatisfactory images require new data acquisition (re-scanning).

Examples of satisfactory and unsatisfactory TOFD images are given in B.1.

12.3 Identification of relevant TOFD indications

Satisfactory TOFD images shall be assessed for the presence of TOFD indications. TOFD indications are identified by patterns or disturbances within the image.

TOFD is able to image discontinuities in the weld as well as geometric features of the test object. In order to identify TOFD indications of geometric features, detailed knowledge of the test object is necessary. Those TOFD indications arising from the intended or actual shape of the test object are considered as non-relevant. Examples of geometric TOFD indications are given in B.3.

To decide whether a TOFD indication is relevant (caused by a discontinuity), patterns or disturbances shall be evaluated considering shape and signal amplitude relative to general noise level. To determine the extent of a TOFD indication, it can be necessary to take into account the grey level values or patterns of neighbouring sections.

12.4 Classification of relevant TOFD indications

12.4.1 General

Amplitude, phase, location and pattern of relevant TOFD indications can contain information on the type of a discontinuity.

Relevant TOFD indications are classified as indications from either surface-breaking or embedded discontinuities by analysing the following features:

a) disturbance of the lateral wave;

b) disturbance of the back-wall reflection;

c) TOFD indications between lateral wave and back-wall reflection;

d) phase of TOFD indications between lateral wave and back-wall reflection;

e) mode-converted signals after the first back-wall reflection.

Some typical TOFD images of discontinuities in fusion-welded joints are provided in B.2.

12.4.2 TOFD indications from surface-breaking discontinuities

12.4.2.1 General

Surface-breaking discontinuities can be classified into three categories (see 12.4.2.2 to 12.4.2.4).

12.4.2.2 Scanning surface discontinuity

This type shows up as an elongated pattern generated by the signal emitted from the lower edge of the discontinuity and a weakening or loss of the lateral wave (not always observed). The TOFD indication from the lower edge can be hidden by the lateral wave, but generally a pattern can be observed in the mode-converted part of the image. For small discontinuities, only a small delay of the lateral wave can be observed.

12.4.2.3 Opposite surface discontinuity

This type shows up as an elongated pattern generated by the signal emitted from the upper edge of the discontinuity and a weakening, loss, or delay of the back-wall reflection (not always observed).

12.4.2.4 Through-wall discontinuity

This type shows up as a loss or weakening of both the lateral wave and the back-wall reflection accompanied by diffracted signals from both ends of the discontinuity.

12.4.3 TOFD indications from embedded discontinuities

12.4.3.1 General

TOFD indications of embedded discontinuities usually do not disturb the lateral wave or the back-wall reflection.

Embedded discontinuities can be classified into three categories (see 12.4.3.2 to 12.4.3.4).

12.4.3.2 Point-like discontinuity

This type shows up as a single hyperbola-shaped curve which can lie at any depth.

12.4.3.3 Elongated discontinuity with no measurable height

This type appears as an elongated pattern corresponding to an apparent upper edge signal.

12.4.3.4 Elongated discontinuity with a measurable height

This type appears as two elongated patterns located at different positions in depth, corresponding to the lower and upper edges of the discontinuity. The TOFD indication of the lower edge is usually in phase with the lateral wave. The TOFD indication of the upper edge is usually in phase with the back-wall reflection.

12.4.4 Unclassified TOFD indications

TOFD indications that cannot be classified in accordance with 12.4.2 and 12.4.3 can require further testing and analysis.

12.5 Determination of location

The location of a discontinuity in the *x*-direction and *z*-direction as defined in ISO 16828 is determined from the data collected in accordance with Clause 11.

The location of a point-like discontinuity is sufficiently described by its *x*-coordinate and *z*-coordinate. The location of elongated discontinuities shall be described by the *x*-coordinates and *z*-coordinates of their extremities.

If the location in the *y*-direction as defined in ISO 16828 is required, additional scans are necessary.

If a more accurate determination of the location is required, reconstruction algorithms, e.g. synthetic aperture focusing calculations (SAFT), may be used.

12.6 Definition and determination of length and height

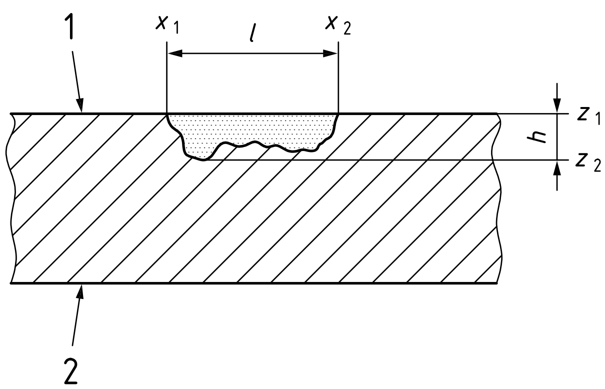
12.6.1 General

The size of a discontinuity is described by the length and height of its indication.

Length is defined by the difference of the *x*-coordinates of the indication.

The height is defined as the maximum difference of the *z*-coordinates at any given *x*-position.

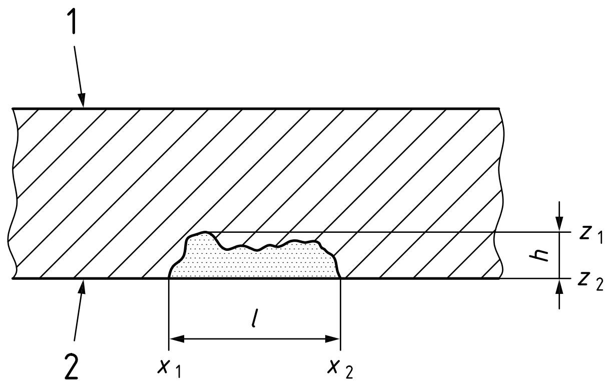
See Figures 1, 2 and 3.



Key

1	scanning surface	z_1	start depth of discontinuity
2	opposite surface	z_2	end depth of discontinuity
x_1	start position of discontinuity	$h = z_2 - z_1$	height
x_2	end position of discontinuity	$l = x_2 - x_1$	length

Figure 1 — Length and height definition of a scanning surface-breaking discontinuity



Key

1 scanning surface

2 opposite surface

x_1 start position of discontinuity

x_2 end position of discontinuity

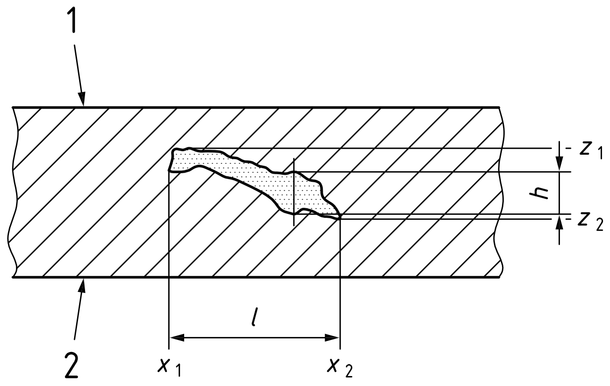
z_1 start depth of discontinuity

z_2 end depth of discontinuity

$h = z_2 - z_1$ height

$l = x_2 - x_1$ length

Figure 2 — Length and height definition of an opposite surface-breaking discontinuity



Key

1 scanning surface

2 opposite surface

x_1 start position of discontinuity

x_2 end position of discontinuity

z_1 start depth of discontinuity

z_2 end depth of discontinuity

h height (not necessarily equal to $z_2 - z_1$)

$l = x_2 - x_1$ length

Figure 3 — Length and height definition of an embedded discontinuity

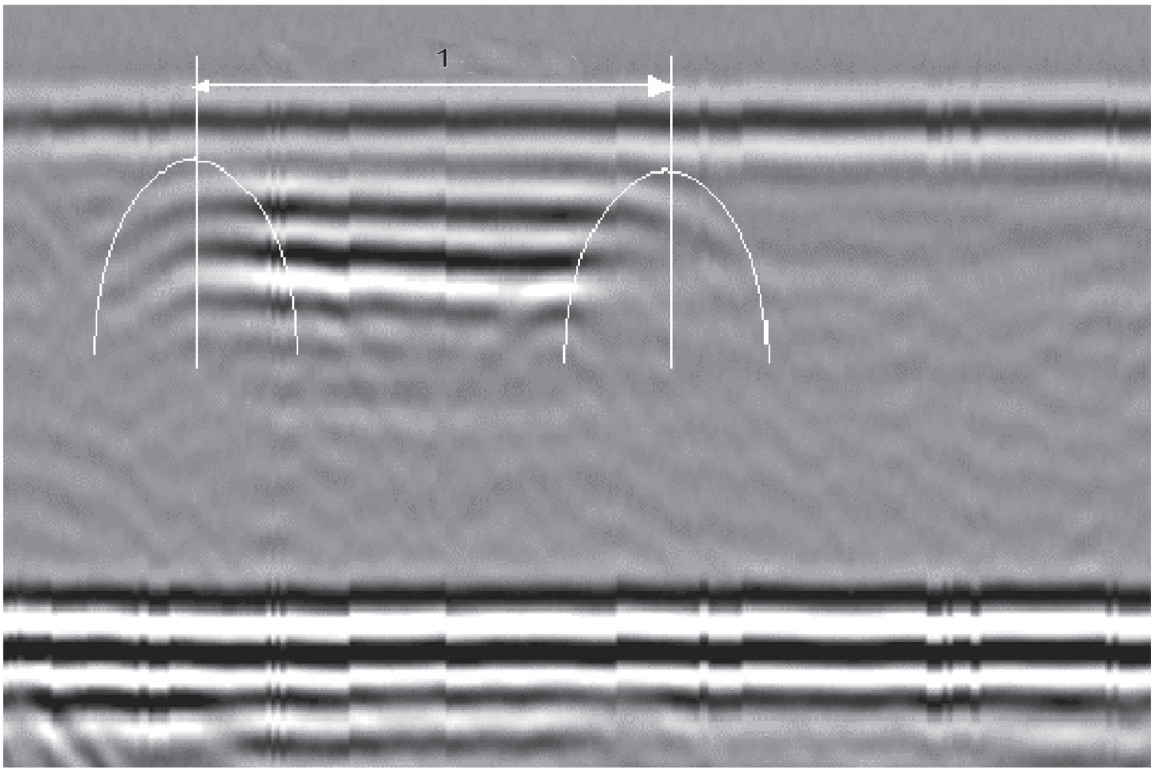
12.6.2 Determination of length

12.6.2.1 General

Depending on the type of indication, one of the techniques for length sizing according to 12.6.2.2 or 12.6.2.3 shall be applied.

12.6.2.2 Length sizing of embedded indications

A hyperbolic cursor is fitted to the indication. Assuming the discontinuity is elongated and has a finite length, this is only possible at each end. The distance moved between acceptable fits at each end of the indication is taken to represent the length of the discontinuity (see Figure 4).



Key

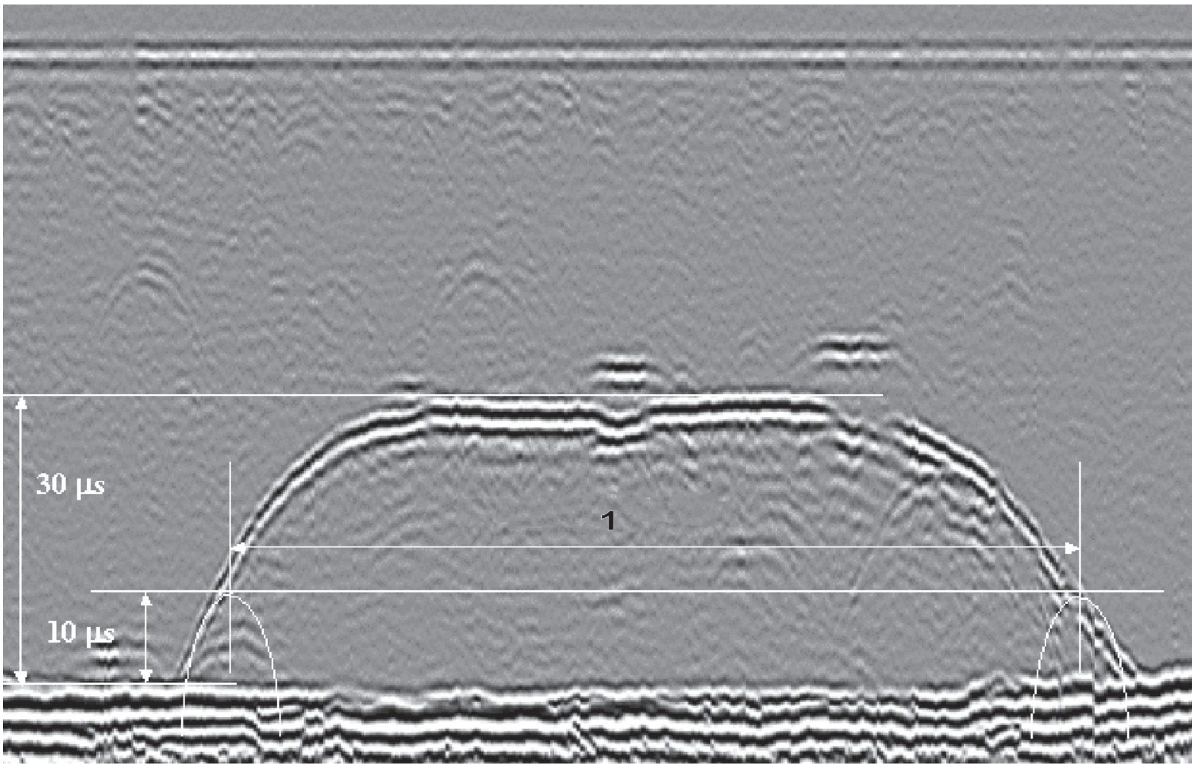
1 length of indication

Figure 4 — Length sizing by fitting hyperbolic cursors

12.6.2.3 Length sizing of elongated curved surface-breaking indications

This type of indication does change significantly in the through-wall direction.

A hyperbolic cursor is positioned at either end of the indication at a time delay of one third of the indication penetration. The distance moved between the cursor positions at each end of the indication is taken to represent the length of the discontinuity (see Figure 5).



Key

1 length of indication

Figure 5 — Length sizing of an elongated curved indication

12.6.3 Determination of height

12.6.3.1 General

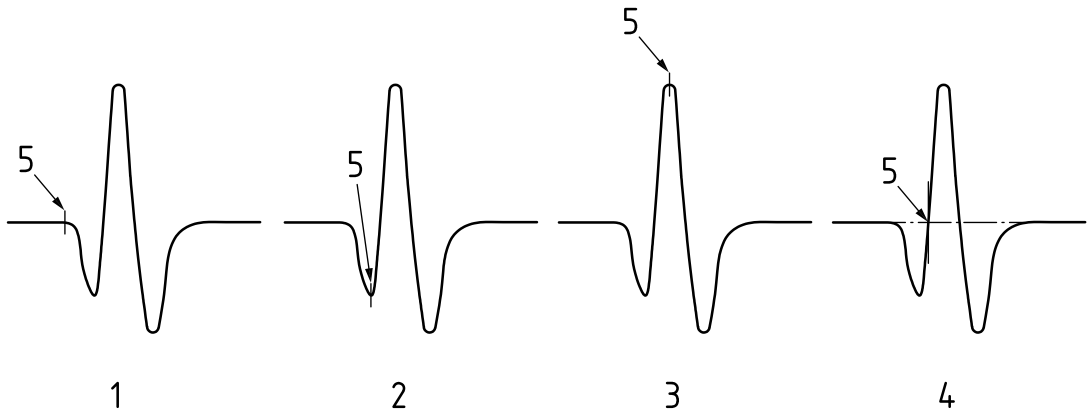
The height determination shall be done from the A-scan and by choosing a consistent position on the signals, if applicable, taking phase reversal into account. It is recommended to use one of the following methods (as shown in Figure 6):

— method 1: by measuring the transit time between the leading edges of the signals;

— method 2: by measuring the transit time between the first peaks;

— method 3: by measuring the transit time between the maximum amplitudes;

— method 4: by measuring the transit time between the first zero crossings of the signals.



Key

1 method 1
2 method 2
3 method 3
4 method 4
5 positions for measuring the transit time

Figure 6 — Positions of the cursor for time measurements — Methods 1, 2, 3 and 4

12.6.3.2 Surface-breaking discontinuities

The height of an indication of a surface-breaking discontinuity at the scanning surface is determined by the maximum difference between the lateral wave and the lower-tip diffraction signal (see Figure 1).

For a surface-breaking discontinuity at the opposite surface, the height is determined by the maximum difference between the upper-tip diffraction signal and the back-wall reflection (see Figure 2).

12.6.3.3 Embedded discontinuities

The height of an indication of an embedded discontinuity is determined by the maximum difference between the upper-tip diffraction signal and the lower-tip diffraction signal at the same *x*-position (see Figure 3).

12.7 Evaluation against acceptance criteria

After classification of all relevant TOFD indications and after determination of their location and size, they shall be evaluated against specified acceptance criteria. Based on this evaluation, the TOFD indications can be categorized as “acceptable” or “not acceptable”.

13 Test report

The test report shall include at least the following information:

a) a reference to this document (i.e. ISO 10863);

b) information relating to the object under test:

   1) identification of the object under test;

   2) dimensions including wall thickness;

   3) material type and product form;

4) geometrical configuration;

5) location of tested welded joint(s);

6) reference to welding process and heat treatment;

7) surface condition and temperature, if outside the range 0 °C to 50 °C;

8) stage of manufacture;

c) information relating to the test equipment:

1) manufacturer and type of the TOFD equipment including scanning mechanisms with identification numbers if required;

2) manufacturer, type, frequency, transducer size and beam angle(s) of the probes with identification numbers if required;

3) details of the reference block(s) with identification numbers if required;

4) type of couplant used;

d) information relating to the test technique:

1) testing level and reference to a written test instruction or procedure, if required;

2) purpose and extent of test;

3) details of datum and co-ordinate systems;

4) details of TOFD setups;

5) method and values used for range and sensitivity settings;

6) details of signal averaging and scan increment setting;

7) details of offset scans, if required;

8) access limitations and deviations from this document, if any;

e) information relating to the test results:

1) acceptance criteria applied;

2) TOFD images of at least those locations where relevant not-acceptable TOFD indications have been detected;

3) tabulated data recording the classification, location and size of relevant TOFD indications and results of the evaluation;

4) date of test;

5) names, signatures and qualification of personnel.

Annex A
(informative)

Reference blocks

A.1 Thickness requirements

A.1.1 General

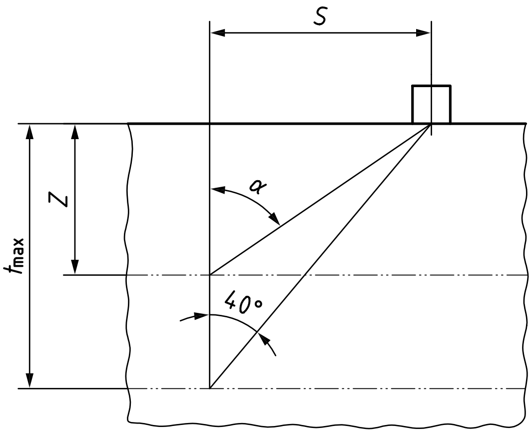
Compliance with 10.3.3, A.1.2 and A.1.3 is recommended for the thickness of reference blocks.

A.1.2 Maximum thickness

The thickness of the reference block should be chosen such that the angle at the bottom of the reference block (as shown in Figure A.1) is not smaller than 40°, in order to avoid having a zone where there is no diffraction at the bottom of the block.

If Z is the depth position of the beam intersection point, $2S$ is the probe centre separation (PCS) and α is the beam angle of the chosen setup then, in accordance with Figure A.1, this maximum thickness, t_{max}, can be calculated by Formula (A.1):

$$\left.\begin{array}{l} S = Z \tan\alpha \\ S = t_{max} \tan 40^\circ \end{array}\right\} \Rightarrow Z \tan\alpha = t_{max} \tan 40^\circ \Rightarrow t_{max} = Z\left(\frac{\tan\alpha}{\tan 40^\circ}\right) \quad \text{(A.1)}$$



Key

t_{max} maximum thickness of reference block

Z depth position of the beam intersection point

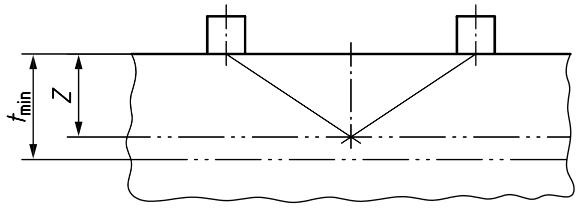
S half PCS

α beam angle

Figure A.1 — Maximum thickness restriction

A.1.3 Minimum thickness

The minimum thickness, t_{min}, of the reference block should be chosen such that the depth position, Z, of the beam intersection point of the chosen setup is always within the reference block (see Figure A.2). This means $t_{min} \geq Z$.



Key

t_{min} minimum thickness of the reference block

Z depth position of the beam intersection point

Figure A.2 — Minimum thickness restriction

A.2 Reference reflectors

For thicknesses between 6 mm and 25 mm, at least three reference reflectors are recommended (see Figures A.4 and A.5). The reflectors may be machined in one or more blocks as follows:

— one notch at the bottom of the block with length, l_n, and height, h_n, (see Table A.1);

— one side-drilled hole located at 4 mm below the surface, with a diameter of 2 mm and a length of 30 mm;

— one side-drilled hole located at $t/2$ below the surface, with a diameter D_d (see Table A.2) and a length of 45 mm. Alternatively, a notch at the scanning-surface with a depth of $t/2$, a tip angle of 60° (see Figure A.3), a width d_{sn} (Table A.2) and a minimum length of 40 mm may be used.

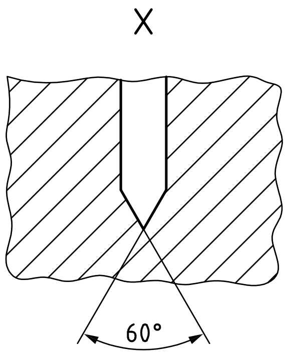


Figure A.3 — Detail of notch tip

For a thickness >25 mm, at least five reference reflectors are recommended (see Figures A.4 and A.5). The reflectors may be machined in one or more blocks as follows:

— one notch at the bottom of the block with length, l_n, and height, h_n (see Table A.1);

— one side-drilled hole located at 4 mm below the surface, with a diameter of 2 mm and a minimum length of 30 mm;

— three side-drilled holes located at $t/4$, $t/2$ and $3t/4$ below the surface, with a diameter D_d (see Table A.2) and a length l (see Table A.3). Alternatively, three notches at the scanning-surface with depths of $t/4$, $t/2$ and $3t/4$, a tip angle of 60° (see Figures A.3 and A.4), a width d_{sn} (see Table A.2) and a minimum length of 40 mm may be used.

The tolerances for all the dimensions are:

— diameter: ±0,2 mm;

— length: ±2 mm;

— angle: ±2°.

Table A.1 — Length and height of the notch in the bottom of the reference block

Thickness *t* mm	**Notch length** l_n mm	**Notch height** h_n mm
6 < *t* ≤ 40	*t*	1 ± 0,2
40 < *t* ≤ 60	40 ± 2	2 ± 0,2
60 < *t* ≤ 100	50 ± 2	2 ± 0,2
t > 100	60 ± 2	3 ± 0,2

Table A.2 — Diameter of the side-drilled holes and width of the surface notches

Thickness *t* mm	**Side-drilled hole diameter** D_d mm	**Surface notch width** d_{sn} mm
6 < *t* ≤ 25	2,5 ± 0,2	2,5 ± 0,2
25 < *t* ≤ 50	3,0 ± 0,2	3,0 ± 0,2
50 < *t* ≤ 100	4,5 ± 0,2	4,5 ± 0,2
t > 100	6,0 ± 0,2	6,0 ± 0,2

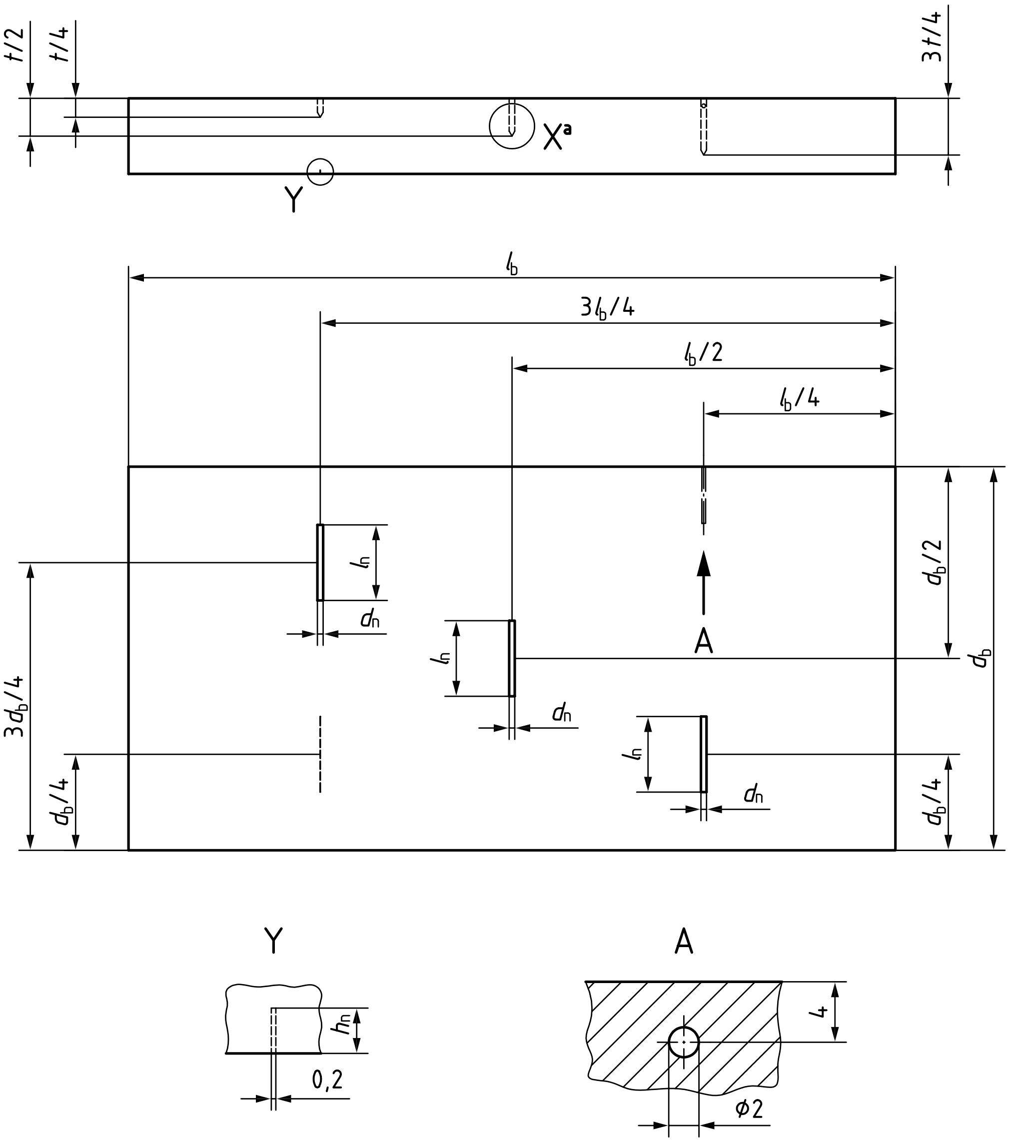
Table A.3 — Length of the side-drilled holes and the surface notches for thickness *t* > 25 mm

epth	**Minimum length**, mm			
	Three holes in the same part	**Three separate parts/ one hole per part**	**Three notches in the same part**	**Three separate parts/ one notch per part**
t/4	l_o = 45	45	40	40
t/2	l_o + 15	45	40	40
3*t*/4	l_o + 30	45	40	40

A.3 Typical reference blocks

Some examples of reference blocks used for TOFD applications containing typical reference reflectors as specified in A.2 are given in Figure A.4 (with notches) and Figure A.5 (with side-drilled holes and a notch).

Dimensions in millimetres



Key

d_b block width

l_b block length

t block thickness

d_n notch width

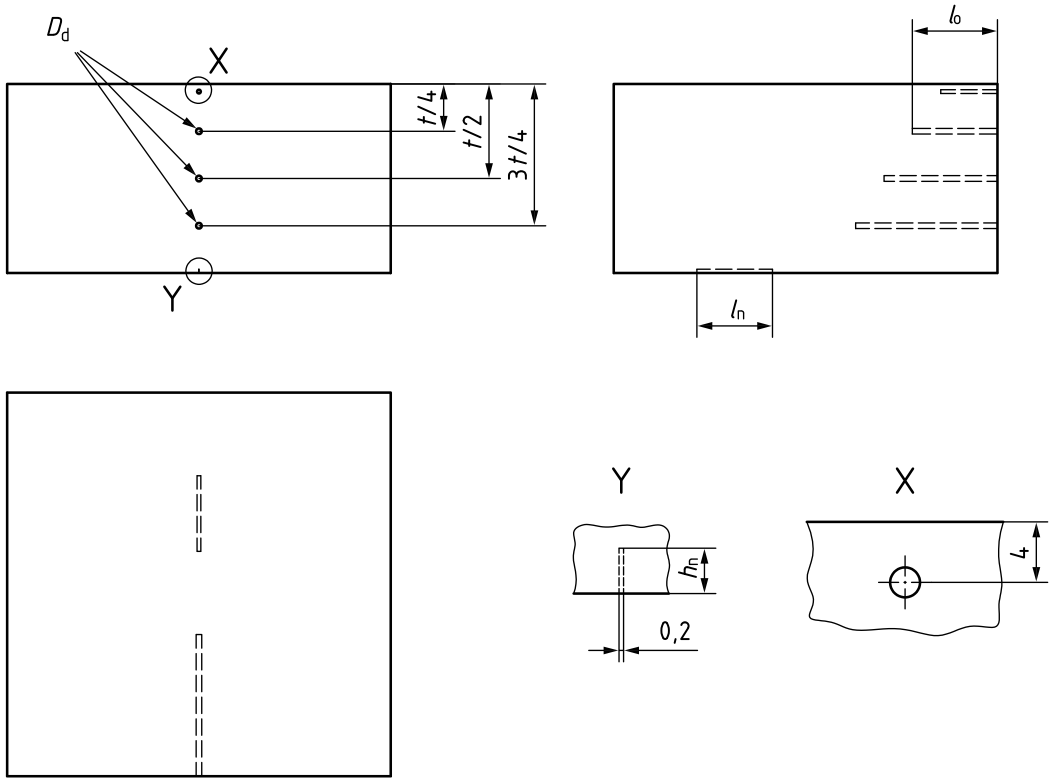
l_n notch length

h_n notch height

a See Figure A.3.

Figure A.4 — Reference block containing notches

Dimensions in millimetres



Key

t block thickness

D_d diameter of side-drilled hole

l_o length of side-drilled hole

l_n bottom notch length

h_n notch height

Figure A.5 — Reference block containing side-drilled holes and a notch

Annex B
(informative)

Examples of TOFD scans

B.1 Satisfactory and unsatisfactory TOFD images

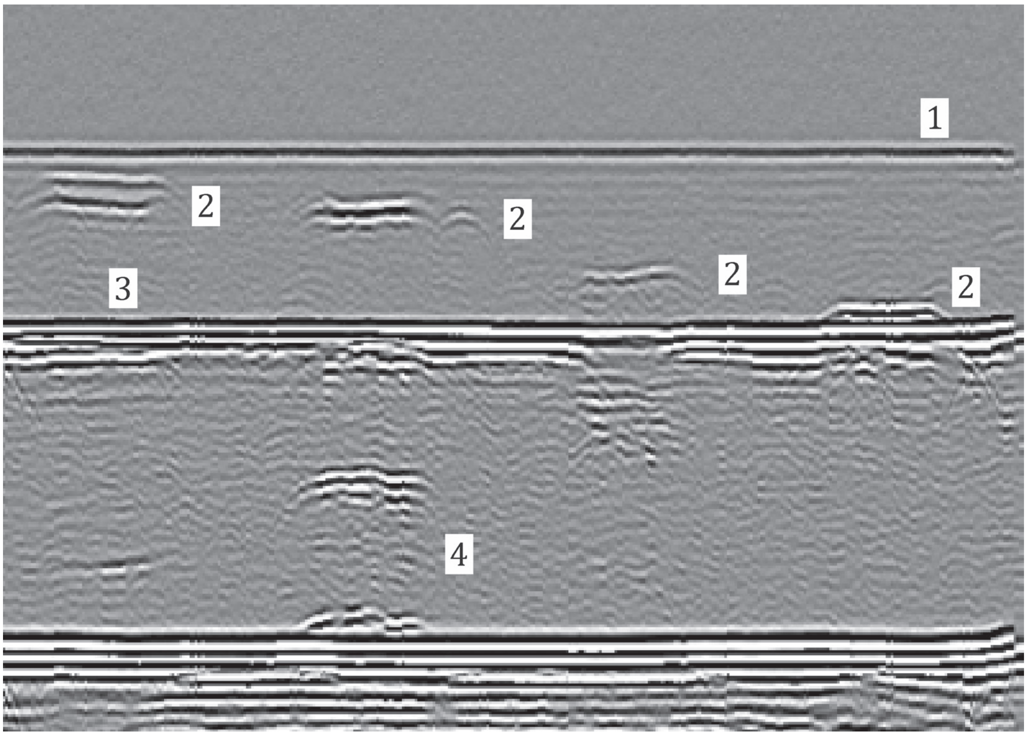
Figure B.1 shows a satisfactory TOFD image, including:

— an undisturbed lateral wave (amplitude between 40 % and 80 % of FSH);

— four TOFD indications of notches in different depths;

— straight back-wall reflection;

— mode-converted signals from notches and back wall.



Key

1 lateral wave

2 indication(s)

3 back-wall reflection

4 mode-converted signal(s)

Figure B.1 — Satisfactory TOFD image

Figures B.2 to B.8 show unsatisfactory TOFD images.

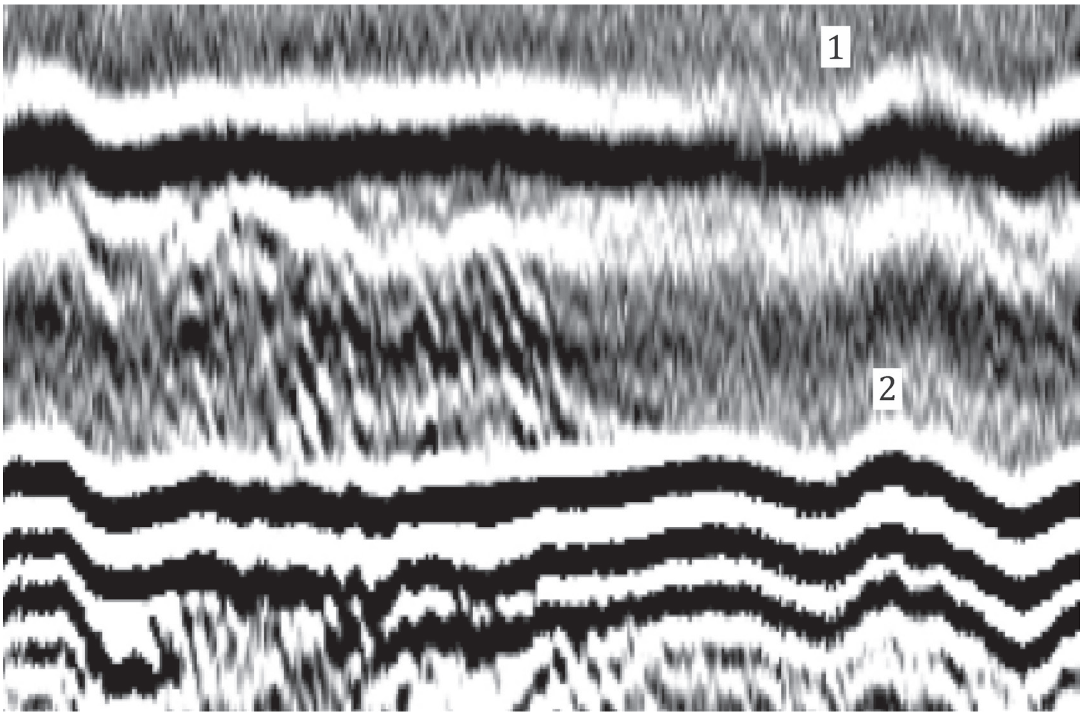
Key

1 lateral wave

2 back-wall reflection

Amplitude of lateral wave <<40 % FSH

Figure B.2 — Gain setting too low



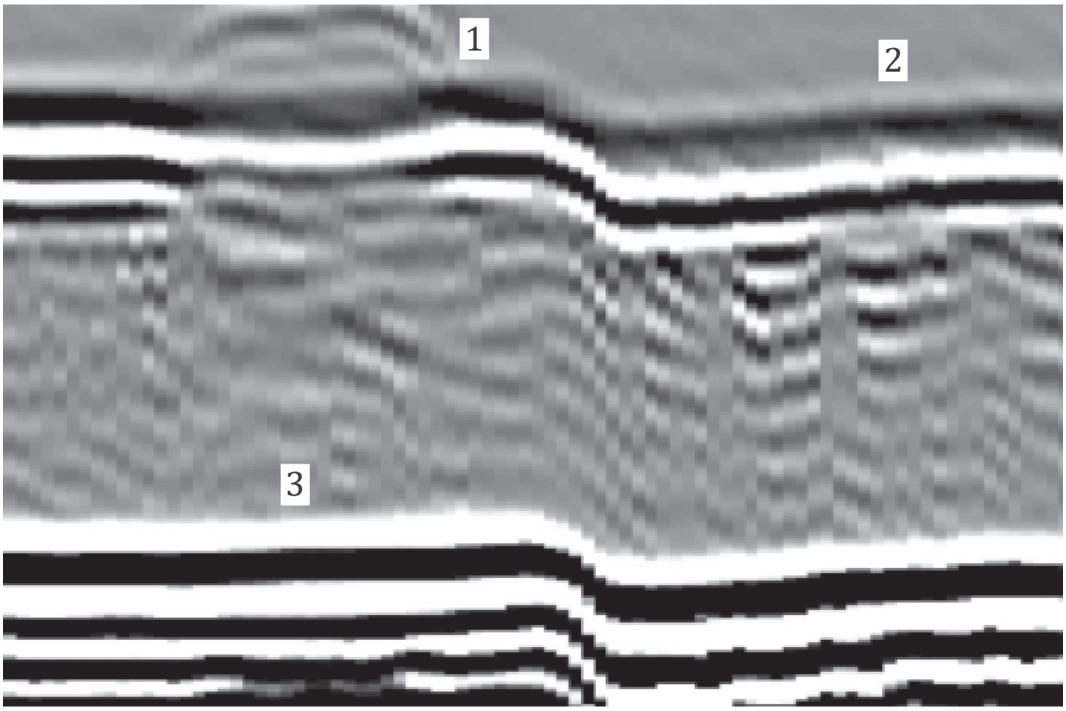
Key

1 lateral wave

2 back-wall reflection

Amplitude of lateral wave >>80 % FSH (saturated)

Figure B.3 — Gain setting too high



Key

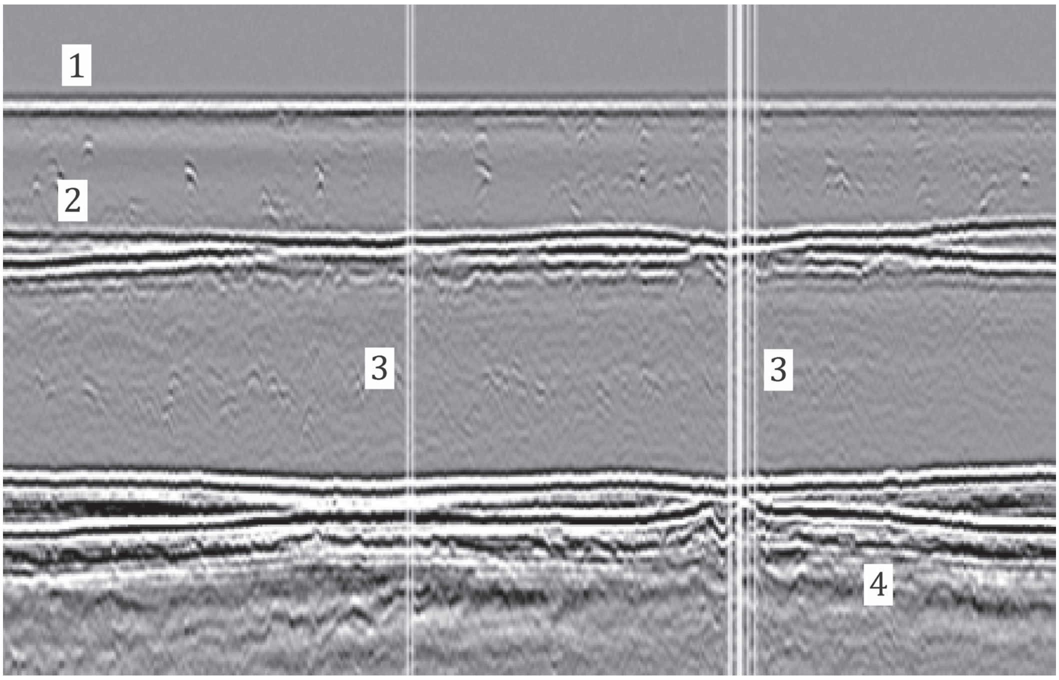
1 indication

2 back-wall reflection

3 mode-converted signal

Lateral wave is not present in the time window.

Figure B.4 — Inappropriate time window setting



Key

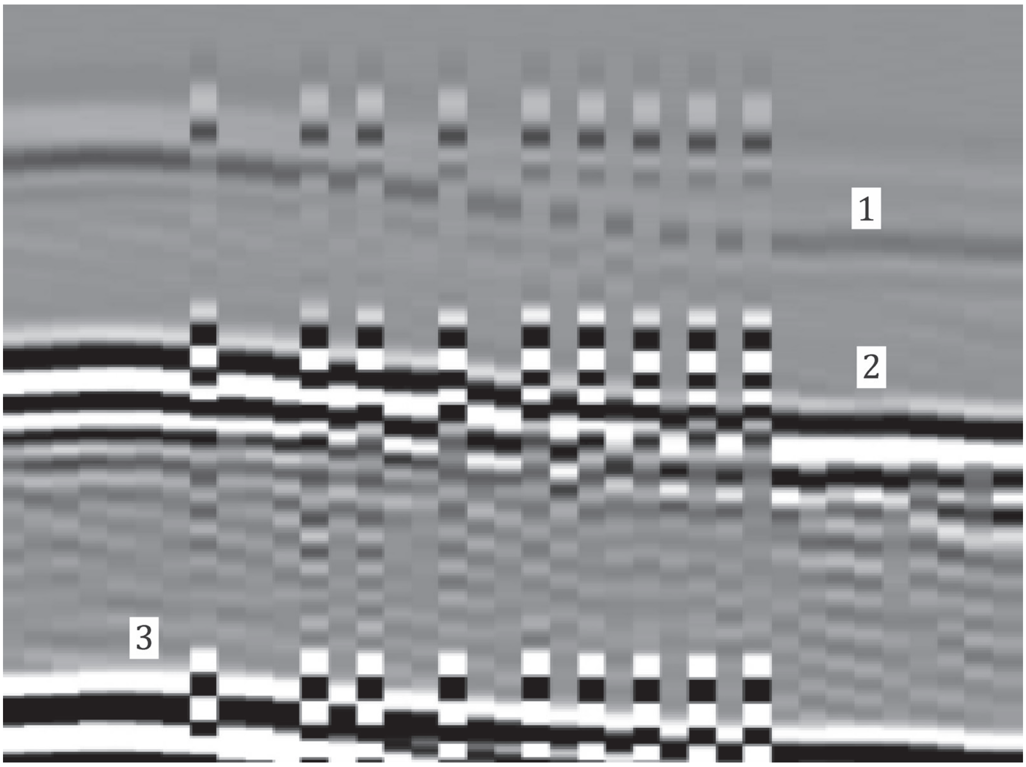
1 lateral wave

2 back-wall reflection

3 missing scan lines

4 mode-converted signal

Figure B.5 — Missing scan lines



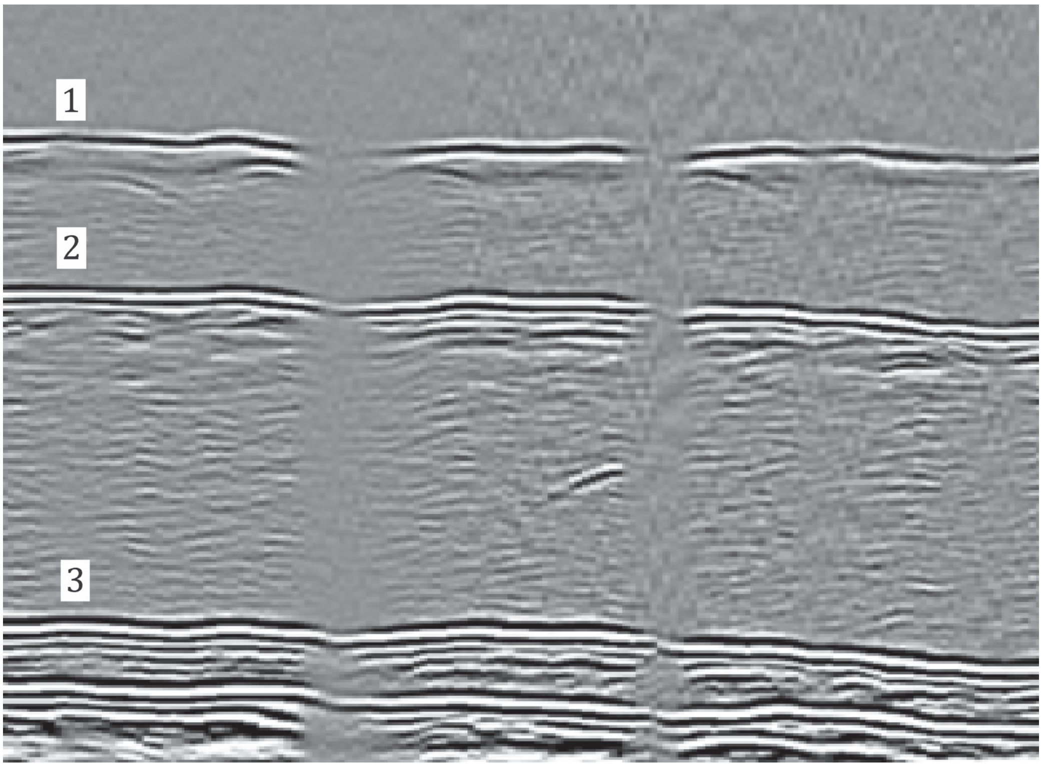
Key

1 lateral wave

2 back-wall reflection

3 mode-converted signal

Figure B.6 — Time-base triggering problems



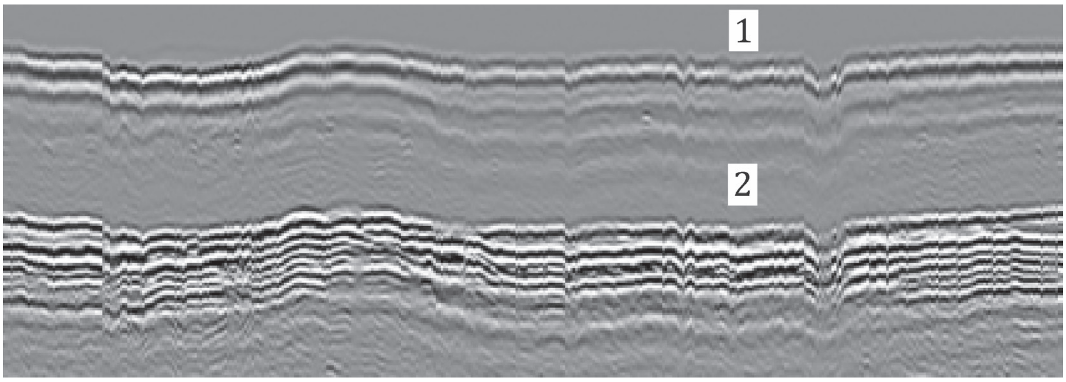
Key

1 lateral wave

2 back-wall reflection

3 mode-converted signal

Figure B.7 — Loss of signals due to lack of couplant



Key

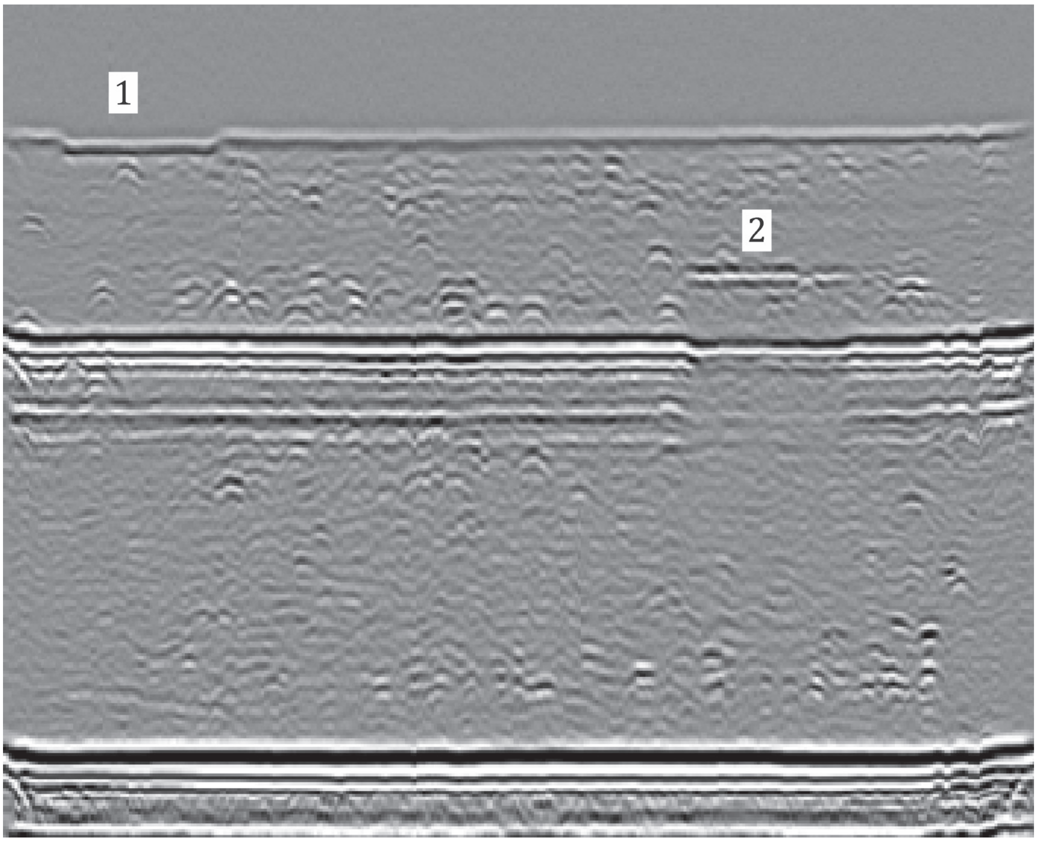
1 lateral wave

2 back-wall reflection

Figure B.8 — Image influenced by variation of couplant layer thickness (may be straightened by software)

B.2 Typical TOFD images of discontinuities in fusion-welded joints

See Figures B.9 to B.14.

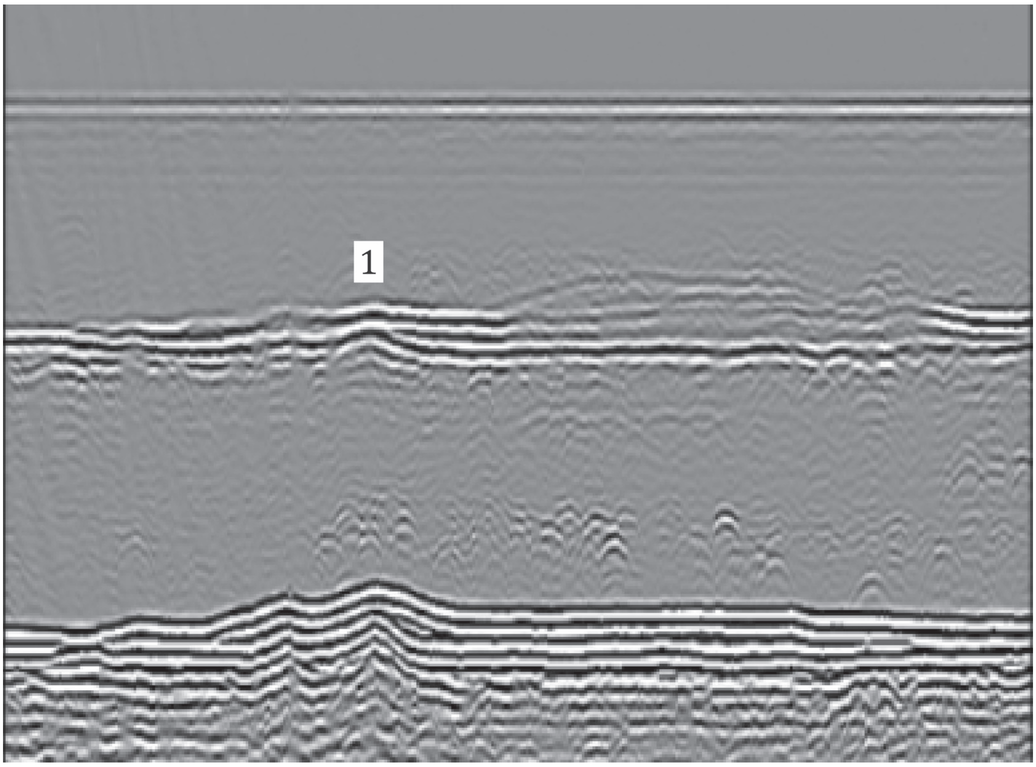


Key

1 scanning surface notch

2 opposite surface notch

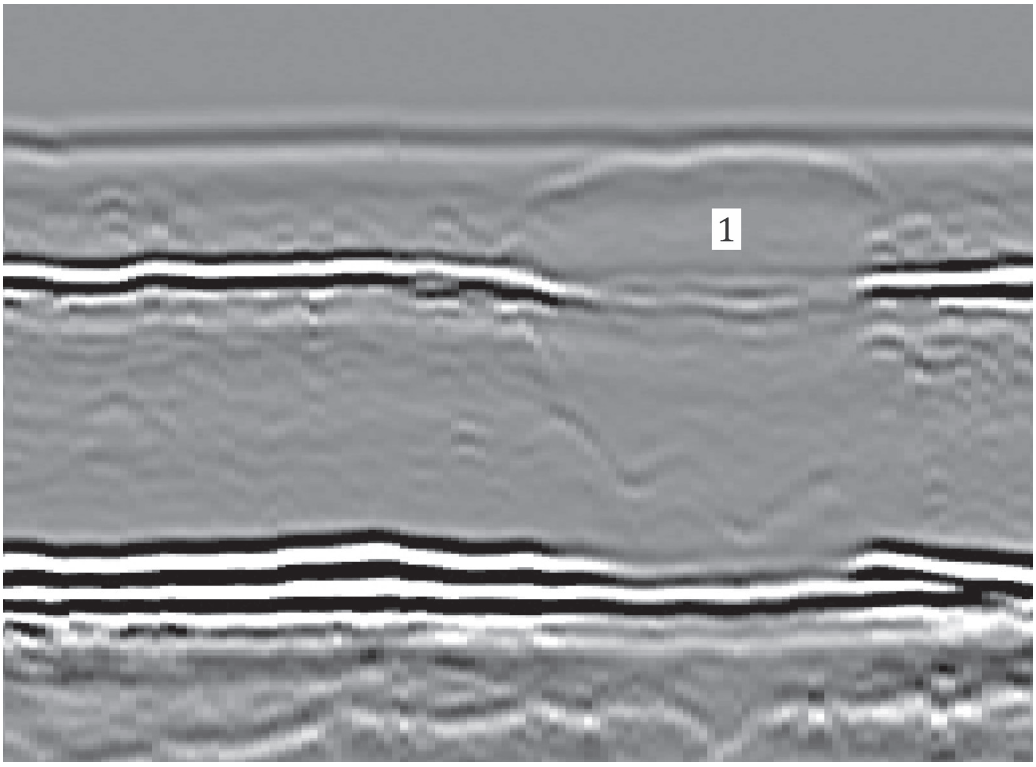
Figure B.9 — TOFD indications of scanning surface notch (disturbance of lateral wave) and of opposite surface notch (straight diffracted signal corresponding to slight disturbance of back-wall signal)



Key

1 opposite surface discontinuity

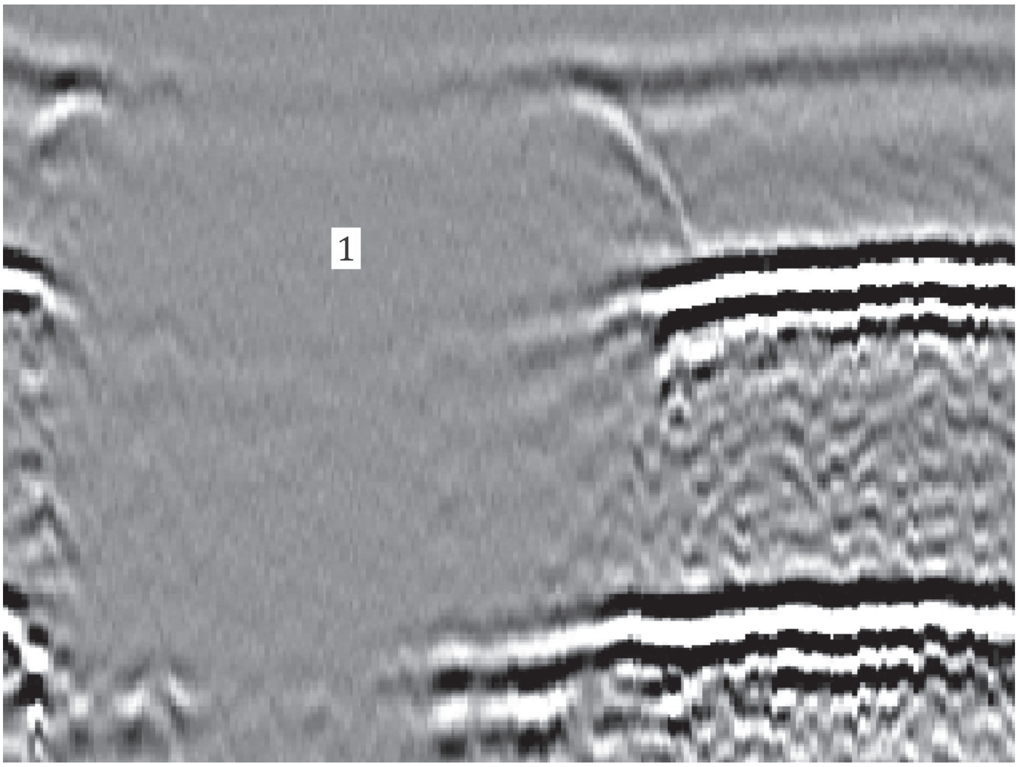
Figure B.10 — Elongated TOFD indication of an opposite surface-breaking discontinuity



Key

1 opposite surface discontinuity

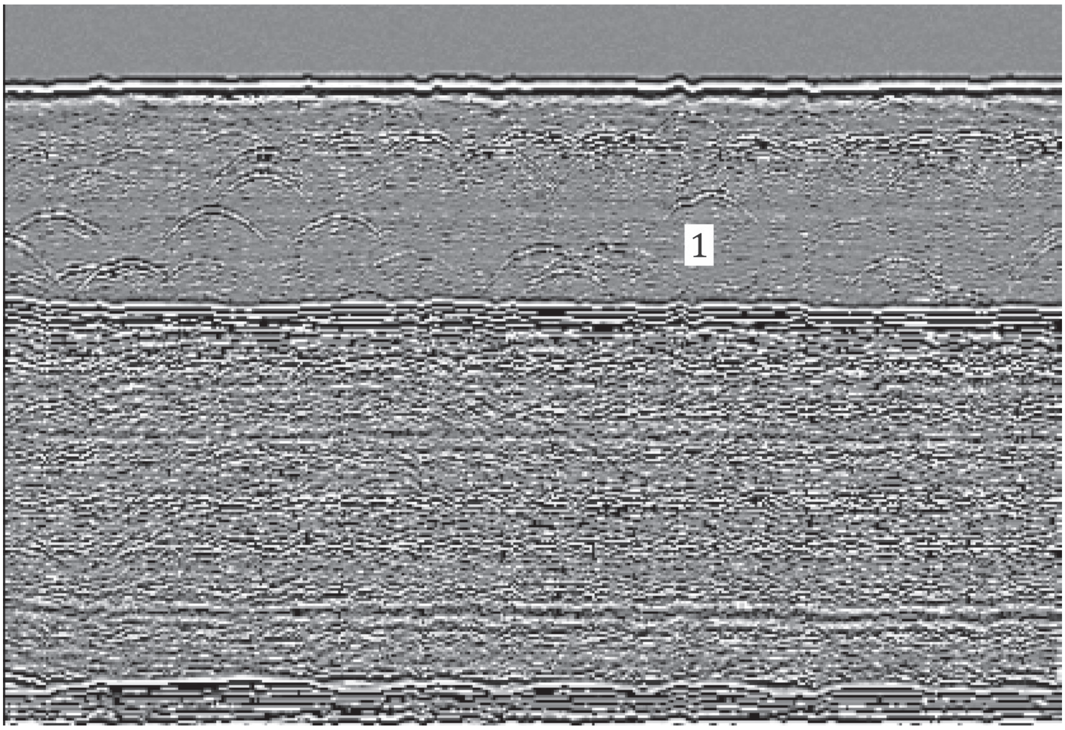
Figure B.11 — Elongated TOFD indication of an opposite surface-breaking discontinuity (nearly through-wall)



Key

1 through-wall discontinuity

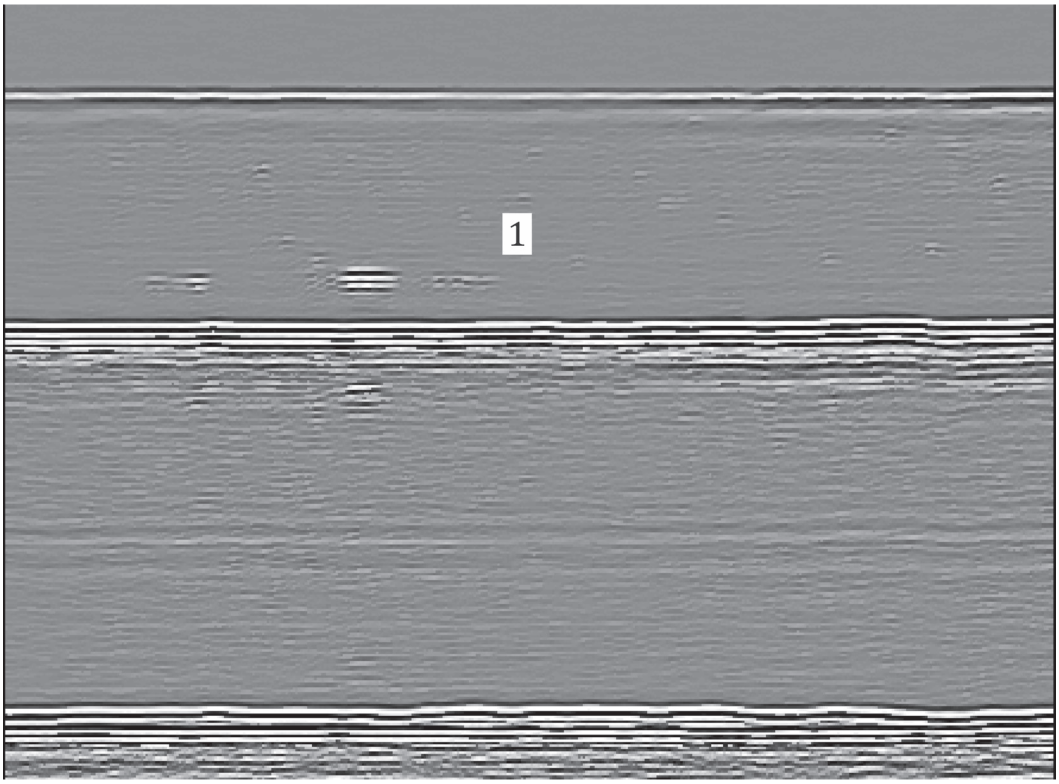
Figure B.12 — TOFD indication of through-wall crack (note the loss of lateral wave and back-wall signal and also the corresponding diffracted signal patterns left and right of this region)



Key

1 point-like discontinuity

Figure B.13 — TOFD indications of multiple point-like discontinuities



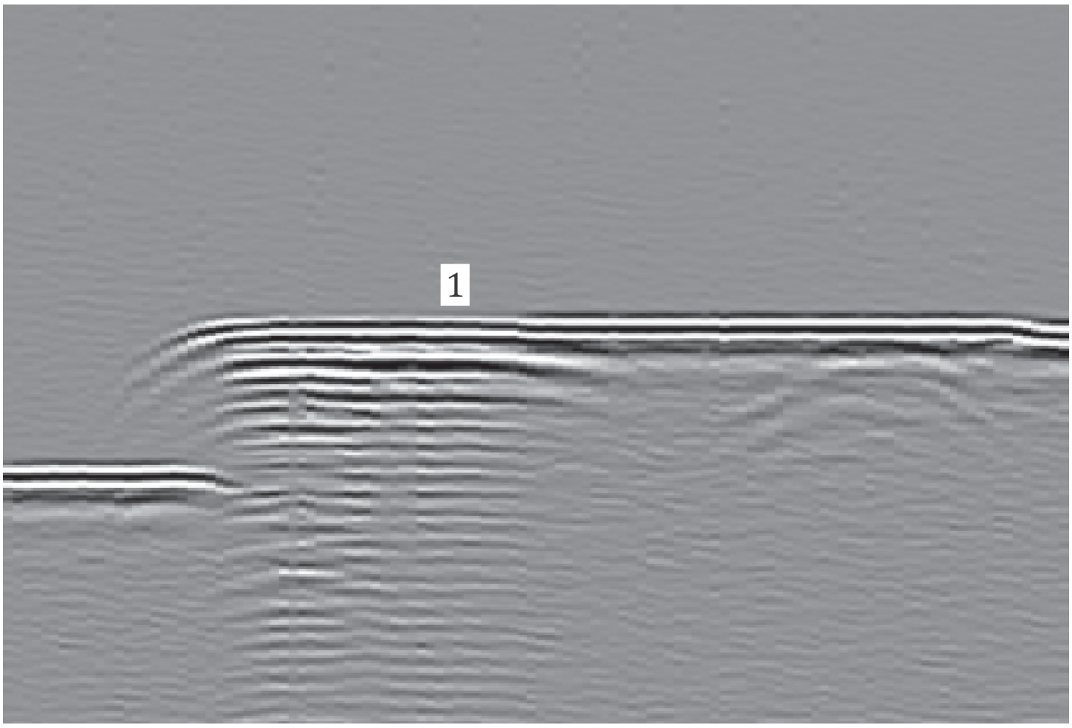
Key

1 elongated discontinuity

Figure B.14 — TOFD indication of an elongated discontinuity with measurable height

B.3 TOFD images of geometrical features

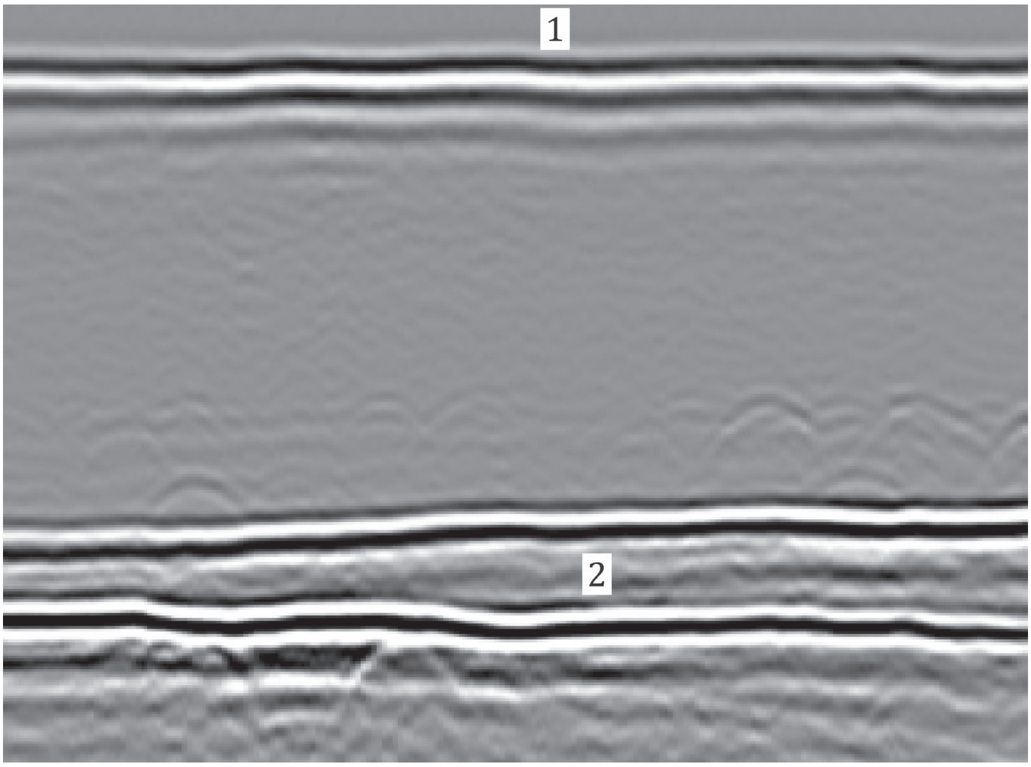
See Figures B.15 to B.18.



Key

1 back-wall reflection

Figure B.15 — TOFD indication of change in wall thickness

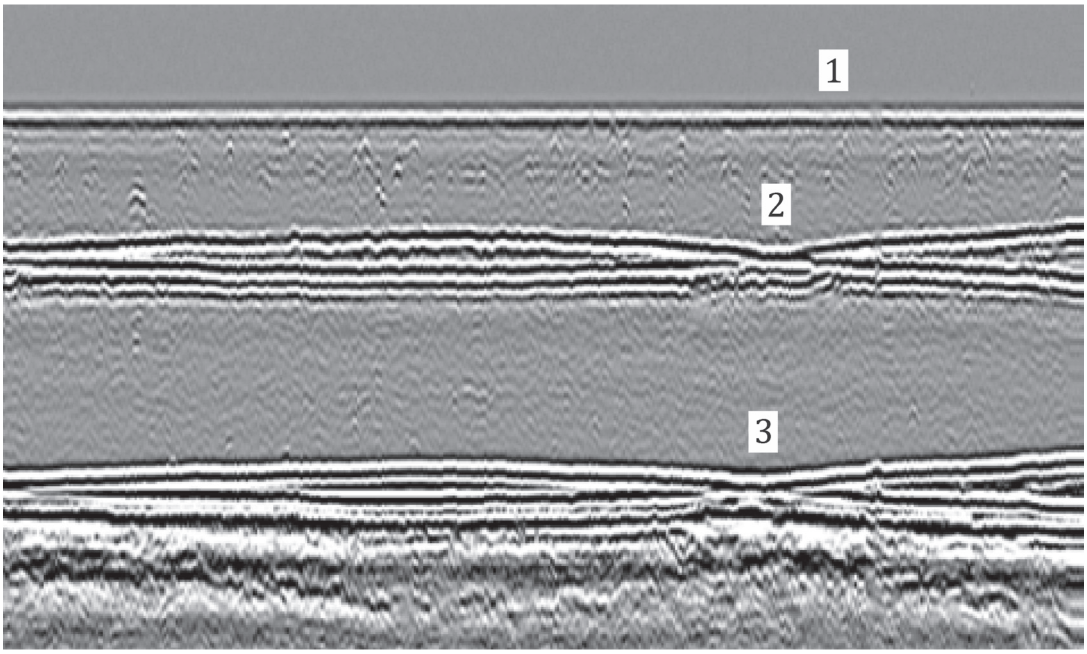


Key

1 lateral wave

2 double back-wall reflection

Figure B.16 — Double back-wall reflection due to different wall thicknesses



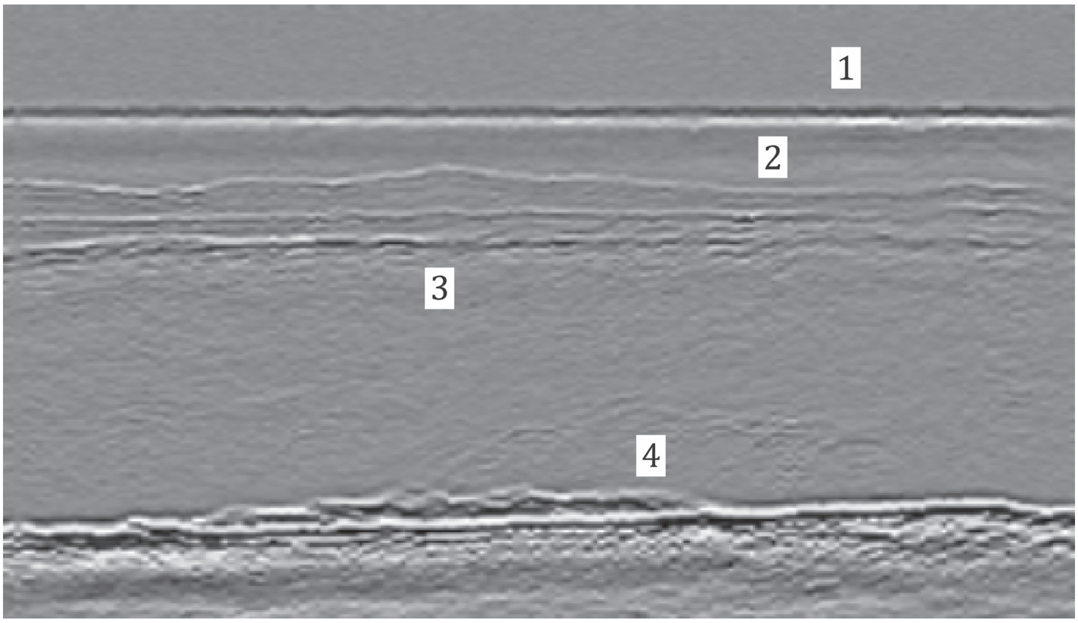
Key

1 lateral wave

2 two back-wall signals

3 mode-converted signals

Figure B.17 — Image of misalignment in circumferentially welded pipes



Key

1 lateral wave

2 root corrosion in the HAZ

3 back-wall signal

4 mode-converted signal

Figure B.18 — TOFD indication of corrosion in the root area on both sides of the weld in the heat-affected zone

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