DRAFT FOR DEVELOPMENT

DD CEN/TS 14751:2004

Welding — Use of time-of-flight diffraction technique (TOFD) for examination of welds

ICS 25.160.40

British Standards

National foreword

This Draft for Development is the official English language version of CEN/TS 14751:2004.

This publication is not to be regarded as a British Standard.

It is being issued in the Draft for Development series of publications and is of a provisional nature because the time-of-flight technique has not been widely used for these applications. It should be applied on this provisional basis, so that information and experience of its practical application may be obtained.

Comments arising from the use of this Draft for Development are requested so that UK experience can be reported to the European organization responsible for its conversion to a European Standard. A review of this publication will be initiated 2 years after its publication by the European organization so that a decision can be taken on its status at the end of its 3-year life. Notification of the start of the review period will be made in an announcement in the appropriate issue of *Update Standards*.

According to the replies received by the end of the review period, the responsible BSI Committee will decide whether to support the conversion into a European Standard, to extend the life of the Technical Specification or to withdraw it. Comments should be sent in writing to the Secretary of BSI Technical Committee WEE/46, Non-destructive testing, at British Standards House, 389 Chiswick High Road, London W4 4AL, giving the document reference and clause number and proposing, where possible, an appropriate revision of the text.

A list of organizations represented on this committee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled "International Standards Correspondence Index", or by using the "Search" facility of the *BSI Electronic Catalogue* or of British Standards Online.

Summary of pages

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TECHNICAL SPECIFICATION

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CEN/TS 14751

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English version

Welding - Use of time-of-flight diffraction technique (TOFD) for examination of welds

Soudage - Utilisation de la technique de diffraction des temps de vol (méthode TOFD) pour le contrôle des soudures

Schweißverbindungen - Anwendung der Beugungslaufzeittechnik (TOFD) für die Prüfung von Schweißverbindungen

This Technical Specification (CEN/TS) was approved by CEN on 11 July 2004 for provisional application.

The period of validity of this CEN/TS is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the CEN/TS can be converted into a European Standard.

CEN members are required to announce the existence of this CEN/TS in the same way as for an EN and to make the CEN/TS available promptly at national level in an appropriate form. It is permissible to keep conflicting national standards in force (in parallel to the CEN/TS) until the final decision about the possible conversion of the CEN/TS into an EN is reached.

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Foreword

This document (CEN/TS 14751:2004) has been prepared by Technical Committee CEN/TC 121 “Welding”, the secretariat of which is held by DIN.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to announce this Technical Specification: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This document specifies the application of the time-of-flight diffraction (TOFD) technique for the semi-, or fully-automated ultrasonic testing of fusion welded joints in metallic materials equal to and above 6 mm thickness. It is primarily intended for use on full penetration welded joints of simple geometry in plates, pipes, and vessels, where both the weld and parent material are low alloyed carbon steel. Where specified and appropriate, TOFD may 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 (5920 ± 50) m/s for longitudinal waves, and (3255 ± 30) m/s for transverse waves. This has to be taken into account when examining materials with a different velocity.

This document makes reference to the basic pre-standard ENV 583-6 and provides guidance on the specific capabilities and limitations of TOFD for the detection, location, sizing and characterisation of discontinuities in fusion welded joints. TOFD may be used as a stand-alone method or in combination with other NDT methods or techniques, both for manufacturing inspection (pre-service) and for in-service inspection.

This document specifies four examination levels (A, B, C, D) corresponding to an increasing level of inspection reliability. Guidance on the selection of examination levels is provided.

This document permits assessment of 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 referenced documents are indispensable for the application 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.

EN 473, *Non destructive testing — Qualification and certification of NDT personnel — General principles.*

EN 583-1, *Non-destructive testing — Ultrasonic examination — Part 1: General principles.*

ENV 583-6, *Non-destructive testing — Ultrasonic examination — Part 6: Time-of-flight diffraction technique as a method for detection and sizing of discontinuities.*

EN 1330-4:2000, *Non-destructive testing — Terminology — Part 4: Terms used in ultrasonic testing.*

EN 1714, *Non destructive examination of welds — Ultrasonic examination of welded joints.*

EN 12062, *Non destructive examination of welds — General rules for metallic materials.*

EN 12668-1, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment — Part 1: Instruments.*

EN 12668-2, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment —Part 2: Probes.*

EN 12668-3, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment —Part 3: Combined equipment.*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1330-4:2000 and the following apply:

3.1
TOFD set-up
probe arrangement defined by probe characteristics (e.g. frequency, probe element-size, beam-angle, wave mode) and probe centre separation (PCS)

3.2
probe centre separation (PCS)
distance between the index-points of the two probes. For curved surfaces it is the shortest distance between the index-points

3.3
beam intersection point
point of intersection of the two main beam-axes

3.4
indication
pattern or disturbance, in the TOFD image which may need further evaluation

3.5
TOFD image
two-dimensional image, constructed by collecting adjacent A-scans while moving the TOFD set-up. The signal-amplitude of the A-scans is typically represented by grey-scale values

3.6
offset-scan
scan parallel to the weld-axis, where the beam intersection point is not on the centre-line of the weld

4 General remarks on the capabilities of the technique

General principles of the TOFD-technique are described in ENV 583-6. For the testing of fusion welded joints some specific capabilities and limitations of the technique have to be considered.

The TOFD technique is an ultrasonic image-generating technique, which offers the capability of detection, location and sizing. To a certain extent characterisation 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 upon 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 (thickness, weld preparation, scope of testing etc) more than one single TOFD set-up is required.

A typical TOFD image is linear in time (vertical axis) and probe movement (horizontal axis). Because of the V-geometry of the ultrasound paths, the location of a possible discontinuity is then non-linear. Similar to the generation of radiographic images, a TOFD testing has to be carried out in a correct and consistent way, such that valid images are generated which can be evaluated correctly. For example coupling losses and data acquisition errors have to 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 has to 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. By example, TOFD can be accompanied by other NDT-methods or -techniques, e.g. conventional pulse-echo testing, see EN 1714.

Diffracted signals from weld-discontinuities have small amplitudes comparable to grain-scatter signals from coarse-grained materials which may hinder the detection and evaluation of discontinuities.

5 Examination levels

This document specifies four examination levels (A, B, C and D). From examination level A to examination level C an increasing reliability will be achieved.

Table 1 — Examination levels

examination level	TOFD set-up	reference block for set-up verification (see 8.2)	reference block for sensitivity settings (see 10.1.4)	offset-scan	Written test instruction
A	acc. to Table 2	no	No	no	this TS
B	acc. to Table 2	no	Yes	no	this TS
C	acc. to Table 2	yes	Yes	[a]	yes
D	as specified	yes	Yes	[a]	yes

[a] the necessity, number of and position of offset scans has to be determined

For pre-service inspections (see also EN 12062) all examination levels are applicable. Level A is only applicable for wall-thickness up to 50 mm. For in-service inspections only examination level D shall be applied.

If the specified acceptance criteria require detection of a certain size of discontinuities at both or one surface of the weld (see Clause 4) this may necessitate the use of techniques or methods outside the scope of this document.

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 Clauses 5 and 8);

b) examination levels (see Clause 5), e.g.
   — whether or not a written test instruction is required;
   — whether or not 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 access and surface conditions (see Clause 8) and temperature;

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 Clause 6.1 together with the following additional information:

a) written test instruction (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 instruction or relevant information on the welding process;

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

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

6.3 Written test instruction

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

Where this is not the case, or where the techniques described in this document are not applicable to the welded joint to be tested, specific written test instructions shall be used.

7 Requirements for personnel and equipment

7.1 Personnel qualifications

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

Preparation of written test instruction, final off-line analysis of data, and acceptance of the report shall be performed by personnel certified as a minimum to level 2 in accordance with EN 473 or equivalent in ultrasonic testing in the relevant industrial sector.

Equipment set-up, data acquisition, data storage, and report preparation shall be performed by personnel certified as a minimum to level 1 in accordance with EN 473 or equivalent in ultrasonic testing in the relevant industrial sector.

For data acquisition the level-1 person 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 Equipment

7.2.1 Ultrasonic equipment and display

Ultrasonic equipment used for the TOFD technique shall, where applicable, comply with the requirements of EN 12668-1, EN 12668-2 and EN 12668-3.

In addition, the requirements of ENV 583-6 shall apply taking into account the following:

- The equipment shall be able to select an appropriate portion of the time base within which A-scans are digitised;
- It is recommended to use a sampling rate of the A-scan of at least 6 times the nominal probe frequency.

7.2.2 Ultrasonic probes

Ultrasonic probes used for the TOFD technique on welds shall comply with ENV 583-6.

Adaptation of probes to curved scanning surfaces shall comply with EN 1714.

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

7.2.3 Scanning mechanisms

The requirements of ENV 583-6 shall apply. To achieve consistency of the images (collected data), guiding mechanisms may be used.

8 Preparation for testing

8.1 Volume to be inspected

Testing shall be performed in accordance with ENV 583-6. The purpose of the testing shall be defined by specification. Based on this the volume to be inspected shall be determined.

The volume to be inspected is located between the probes. For examination levels A and B the probes shall be placed symmetrically to the weld centre line. For examination levels C and D additional offset-scans may be required.

For manufacturing examinations (pre-service inspection) the examination volume 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 examination volume shall be covered.

Normally these examinations are carried out according to recognised 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 examination volume may be targeted to specify areas of interest, e.g. the inner 1/3 of the weld body. The acceptance criteria and minimum size discontinuity to be detected in the area of interest shall be specified.

8.2 Set up 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 set-ups (scans) dependent upon 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, effectiveness and coverage shall be verified by the use of reference blocks.

Selection of probes for full coverage of the complete weld thickness (typically pre-service inspection) 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 an element-size of 3 mm may be appropriate for a thickness of 16 mm but not for 32 mm.

If set-up parameters are not in accordance with Table 2, the capability shall be verified by the use of reference blocks.

For examination levels C and D, all the set-ups chosen for the test object shall be verified by use of reference blocks.

For in-service inspection the intersection point of the beam centre lines should be optimised for the specified examination volume.

Table 2 — Recommended TOFD set-ups for simple butt-welds dependent on wall-thickness

Thickness t / mm	Number of TOFD set-ups	Depth-range Δt / mm	Centre-frequency f / MHz	Beam-angle α / ° (long.-waves)	Element – size / mm	Beam intersection
6-10	1	0-t	15	70	2-3	2/3 of t
10-15	1	0-t	15-10	70	2-3	2/3 of t
15-35	1	0-t	10-5	70-60	2-6	2/3 of t
35-50	1	0-t	5-3	70-60	3-6	2/3 of t
50-100	2	0-t/2	5-3	70-60	3-6	1/3 of t
		t/2-t	5-3	60-45	6-12	5/6 of t; or t for $\alpha \leq 45°$
100-200	3	0-t/3	5-3	70-60	3-6	2/9 of t
		t/3-2t/3	5-3	60-45	6-12	5/9 of t
		2/3t-t	5-2	60-45	6-20	8/9 of t; or t for $\alpha \leq 45°$
200-300	4	0-t/4	5-3	70-60	3-6	1/12 of t
		t/4-t/2	5-3	60-45	6-12	5/12 of t
		t/2-3t/4	5-2	60-45	6-20	8/12 of t
		3t/4-t	3-1	50-40	10-20	11/12 of t; or t for $\alpha \leq 45°$

8.3 Scan increment setting

The scan increment setting is dependent upon the wall thickness to be examined. For thickness up to 10 mm the scan increment shall be no more than 0,5 mm. For thickness between 10 mm and 150 mm the scan increment shall be no more than 1 mm. Above 150 mm a scan increment of 2 mm can be used.

8.4 Geometry considerations

Care should be taken when examining 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 upon 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 may be obscured. Additional scans may in many cases overcome this problem. Planning examinations 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 the examination volume to be fully covered.

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, R_a, 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 object under examination shall be in the range of 0 °C – 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 material.

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

Prior to the TOFD-weld-testing the base material does not generally need to be inspected for laminations (typically by using ultrasonic testing with straight beam probes), as they will be detected during the TOFD-weld-testing. Nevertheless, the presence of discontinuities in the base material adjacent to the weld may 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 shall be carried out prior to each testing in accordance with this document and ENV 583-6. Any change of the TOFD set-up, e.g. probe centre separation (PCS), requires a new setting.

Noise should be minimised 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:

- For full-thickness testing using only one set-up, the time window recorded should start at least 1 µs prior to the time of arrival of the lateral wave, and should where possible extend up to the first mode converted backwall signal.

- If more than one set-up is used, the time windows shall overlap at least 10 % of the depth-range.

The start and extent of the time windows have to 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 backwall signal with a known material velocity.

This setting has to be verified by a suitable block of known thickness (accuracy 0,05 mm). At least one depth measurement has to 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 may be necessary.

10.1.4 Sensitivity settings

For all examination levels the sensitivity shall be set on the test object. The amplitude of the lateral wave shall be between 40 % and 80 % full screen height (FSH). In cases where the use of the lateral wave is not appropriate (e.g. 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 % FSH.

For examination levels B, C, and D, the sensitivity shall be verified by use of a

- reference block containing real discontinuities in the respective depth-zone or if not available by a

- reference block containing machined discontinuities (notches, side-drilled holes, etc.), see 10.3.

10.2 Checking of the settings

Checking of the settings is to be performed at least every four hours and after completion of the testing. If a reference block was used for initial setting, the same reference block shall be used for checking. Alternatively, a smaller block with known transfer properties may be used.

Where no reference block was used, then the checking shall be carried out at the same location (position on the component) as the initial setting.

If deviations are found during these checks the corrections given in Table 3 shall be carried out.

Table 3 — Sensitivity and range corrections

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

10.3 Reference blocks

10.3.1 General

Depending on the examination level, a reference block shall be used to determine the adequacy of the testing (e.g. coverage, sensitivity setting). Recommendations for reference blocks are shown 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 for 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 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 set-up 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 defects can be properly scanned.

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

10.3.4 Reference reflectors

For a thickness between 6 mm and 25 mm at least 3 reflectors are required, for a thickness t > 25 mm at least 5 reflectors are required. Typical reference reflectors are side-drilled holes and notches.

11 Weld testing

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

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

Scanning speed shall be chosen such that satisfactory images are generated, see 12.1. The scanning speed is dependent on scan increment, signal averaging, pulse-repetition frequency, data acquisition frequency and the volume to be inspected. Missing scan lines indicate that a too high velocity 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, backwall-signal, grain-noise, or mode-converted signals during a scan by more than 12 dB may indicate loss of coupling (see Annex B.1.7 and B.1.8). If coupling loss is suspected, the area shall be rescanned. If the results are still not satisfactory, appropriate action shall be taken.

Saturation of the lateral wave or excessive grain noise (> 20 % FSH) during scanning requires gain reduction and rescanning.

12 Interpretation and analysis of TOFD images

12.1 General

Interpretation and analysis of TOFD images is generally performed as follows:

- Assessing the quality of the TOFD-image;
- Identification of relevant indications and discrimination of non-relevant indications;
- Classification of relevant indications in terms of:
  - embedded (linear, point-like);
  - surface breaking;
- Determination of location (typically position in x- and z-direction) and size (length and through-wall extent);
- Evaluation against acceptance criteria.

12.2 Assessing the quality of the TOFD image

A TOFD-testing has to be carried out such that satisfactory images are generated which can be evaluated with confidence. Satisfactory images are defined by appropriate:

- coupling, see 8.7 and Clause 11;
- coupling, see 8.7 and Clause 11;
- data acquisition, see Clause 11;
- sensitivity setting, see 10.1.4;
- time-base setting, see 10.1.2.

Assessing the quality of TOFD-images requires skilled and experienced operators, see 7.1. The operator has to decide whether non-satisfactory images require new data acquisition (rescanning).

Examples of non-satisfactory images are given in Annex B.1.

12.3 Identification of relevant indications

Satisfactory TOFD images shall be assessed for the presence of indications. 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 indications of geometric features, detailed knowledge of the test object is necessary. Those indications arising from the intended or actual shape of the test object are considered as non-relevant. Examples of geometric indications are given in Annex B.3.

To decide whether an indication is relevant (caused by a discontinuity), patterns or disturbances have to be evaluated considering shape and signal amplitude relative to general noise level. The extent of an indication may need to take account of grey level values or patterns of neighbouring sections.

12.4 Classification of relevant indications

12.4.1 General

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

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

a) disturbance of the lateral wave;
b) disturbance of the backwall reflection;
c) indications between lateral wave and backwall reflection;
d) phase of indications between lateral wave and backwall reflection;
e) mode converted signals after the first backwall reflection.

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

12.4.2 Indications from surface breaking discontinuities

Surface breaking discontinuities can be classified into three categories:

1. 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 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 may be observed.

2. 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 backwall reflection (not always observed).

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

12.4.3 Indications from embedded discontinuities

Embedded discontinuities can be classified into three categories:

1. Point-like discontinuity:
This type shows up as a single hyperbolic shaped curve which may lie at any depth.

2. Elongated discontinuity with no measurable height:
This type appears as an elongated pattern corresponding to an apparent upper edge signal.

3. 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 indication of the lower edge is usually in phase with the lateral wave. The indication of the upper edge is usually in phase with the back wall reflection.

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

12.4.4 Unclassified indications

Indications that cannot be classified in accordance with 12.4.2 and 12.4.3 may require further testing and analysis.

12.5 Determination of location and size

12.5.1 Location

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

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

If the location in the y-direction is required, additional scans are necessary.

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

12.5.2 Sizing

The size of a discontinuity is determined by its length and height. Length is defined by the difference of the x-coordinates of the extremities of the indication. The height is defined as the maximum difference of the z-coordinates. For indications displaying varying z-coordinates along their length, the height should be determined at the x-position where the difference of the z-coordinates is greatest.

12.6 Evaluation against acceptance criteria

After classification of all relevant indications and determination of their location and size, they should be evaluated against specified acceptance criteria and acceptance levels, respectively.

Based upon this evaluation the indications can be categorised as “acceptable” or “not acceptable”.

13 Test report

13.1 General

The test report shall include a reference to this document and shall give, as a minimum, the following information:

13.2 Information relating to object under test

a) identification of object under test;
b) dimensions including wall thickness;
c) material type and product form;
d) geometrical configuration;
e) location of welded joint(s) examined;
f) reference to welding process and heat treatment;
g) surface condition and temperature, if outside the range 0 °C to 50 °C;
h) stage of manufacture.

13.3 Information relating to equipment

a) manufacturer and type of TOFD equipment including scanning mechanisms with identification numbers if required;
b) manufacturer, type, frequency, element size and beam angle(s) of probes with identification numbers if required;
c) details of reference block(s) with identification numbers if required;
d) type of couplant used.

13.4 Information relating to test technique

a) examination level and reference to a written test instruction, if required;
b) purpose and extent of test;
c) details of datum and co-ordinate systems;
d) details of TOFD set-ups;
e) method and values used for range and sensitivity settings;
f) details of signal averaging and scan increment setting;
g) details of offset scans, if required;
h) access limitations and deviations from this document, if any.

13.5 Information relating to test results

a) TOFD images of at least those locations where relevant indications have been detected;
b) acceptance criteria applied;
c) tabulated data recording the classification, location and size of relevant indications and results of evaluation;
d) date of test;
e) names, signatures and certification of personnel.

Annex A
(informative)

Reference blocks

A.1 Thickness requirements

A.1.1 Maximum thickness

The thickness of the reference block should be chosen such that the beam angle at the bottom of the reference block is not smaller than 40°, in order to avoid having a zone where there is no diffraction at the bottom of the block. According to the following drawing this maximum thickness (T_{max}) can be calculated as follows:

$S = Z \tan \alpha$ and $S = T_{max} \tan 40° \Rightarrow Z \tan \alpha = T_{max} \tan 40° \Rightarrow T_{max} = (Z \tan \alpha)/\tan 40°$

where Z is the focus point and α is the beam angle of the chosen set-up.

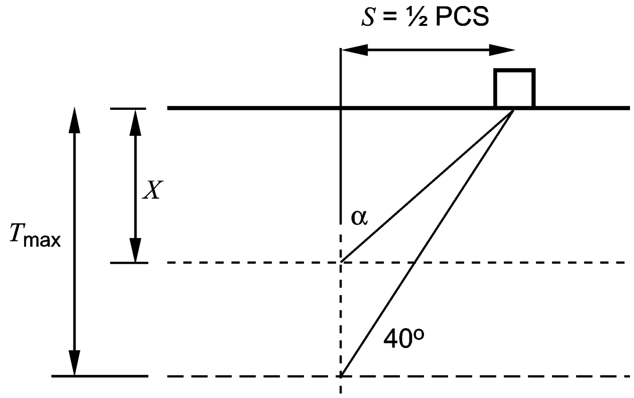


Figure A.1 — Maximum thickness restriction

For example, when t = 35 mm and α = 60° then with $Z = {}^2/_3\, t$ = 23,3 mm then:

T_{max}= (23,3 tan 60°)/tan 40° = 48,1 mm.

A.1.2 Minimum thickness

The minimum thickness of the reference block should be chosen such that the beam intersection point (Z) of the chosen set-up is always within the reference block, see Figure A.2.

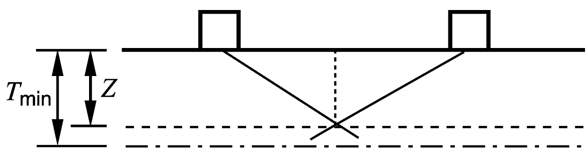


Figure A.2 — Minimum thickness restriction

This means: $T_{min} \geq Z$.

A.2 Reference reflectors

For a thickness between 6 mm and 25 mm at least 3 reference reflectors are recommended. The reflectors may be machined in one or more blocks:

- One notch at the bottom of the block with length X and height h (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 ½ t below the surface, with a diameter D_d (Table A.2) and a length of 45 mm. Alternatively a notch at the scanning-surface with a depth of ½ t, a tip angle of 60° (see Figure A.3), a width w (Table A.2) and a minimum length of 40 mm may be used.

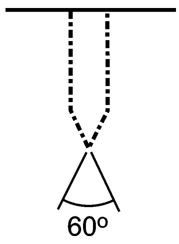


Figure A.3 — Detail of notch tip

For a thickness > 25 mm at least 5 reference reflectors are recommended. The reflectors may be machined in one or more blocks:

- one notch at the bottom of the block with length X and height h (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 ¼ t, ½ t and ¾ t below the surface, with a diameter D_d (Table A.2) and a length l (Table A.3). Alternatively three notches at the scanning-surface with depths of ¼ t, ½ t and ¾ t, a tip angle of 60° (see Figure A.3), a width w (Table A.2) and a minimum length of 40 mm may be used.

The tolerances for all the dimensions are as follows:

- diameter: ± 0,2 mm
- length: ± 2 mm
- angle: ± 2°

Table A.1 — Length and height of the notch near the bottom

Thickness [mm]	X [mm]	h [mm]
$6 < t \leq 40$	t	1 ± 0,2
$40 < t \leq 60$	40 ± 2	2 ± 0,2
$60 < t \leq 100$	50 ± 2	2 ± 0,2
$t > 100$	60 ± 2	3 ± 0,2

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

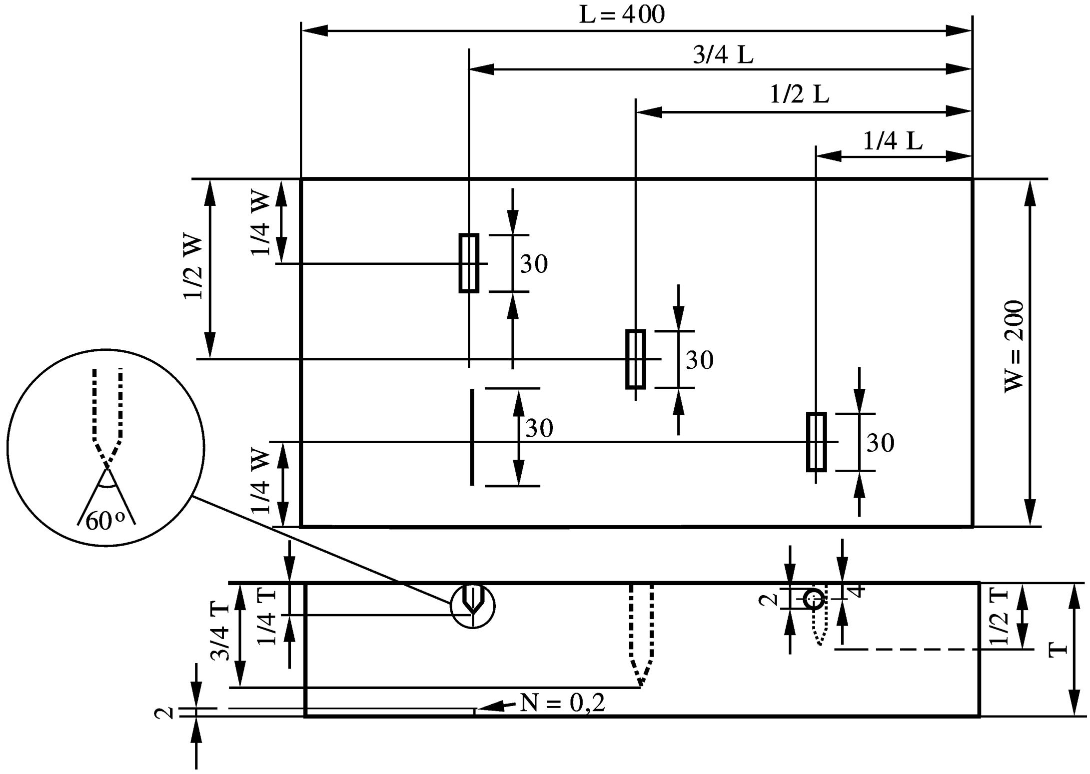
Thickness [mm]	D_d [mm] / w [mm]
$6 < t \leq 25$	2,5 ± 0,2
$25 < t \leq 50$	3,0 ± 0,2
$50 < t \leq 100$	4,5 ± 0,2
$t > 100$	6,0 ± 0,2

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

	3 holes in the same part	3 separated parts / 1 hole per part	3 notches in the same part	3 separated part / 1 notch per part
Depth	**Minimum length (mm)**	**Minimum length (mm)**	**Minimum length (mm)**	**Minimum Length (mm)**
¼ t	$l_0 = 45$	45	40	40
½ t	$l_0 + 15$	45	40	40
¾ t	$l_0 + 30$	45	40	40

A.3 Typical reference blocks

Dimensions in mm

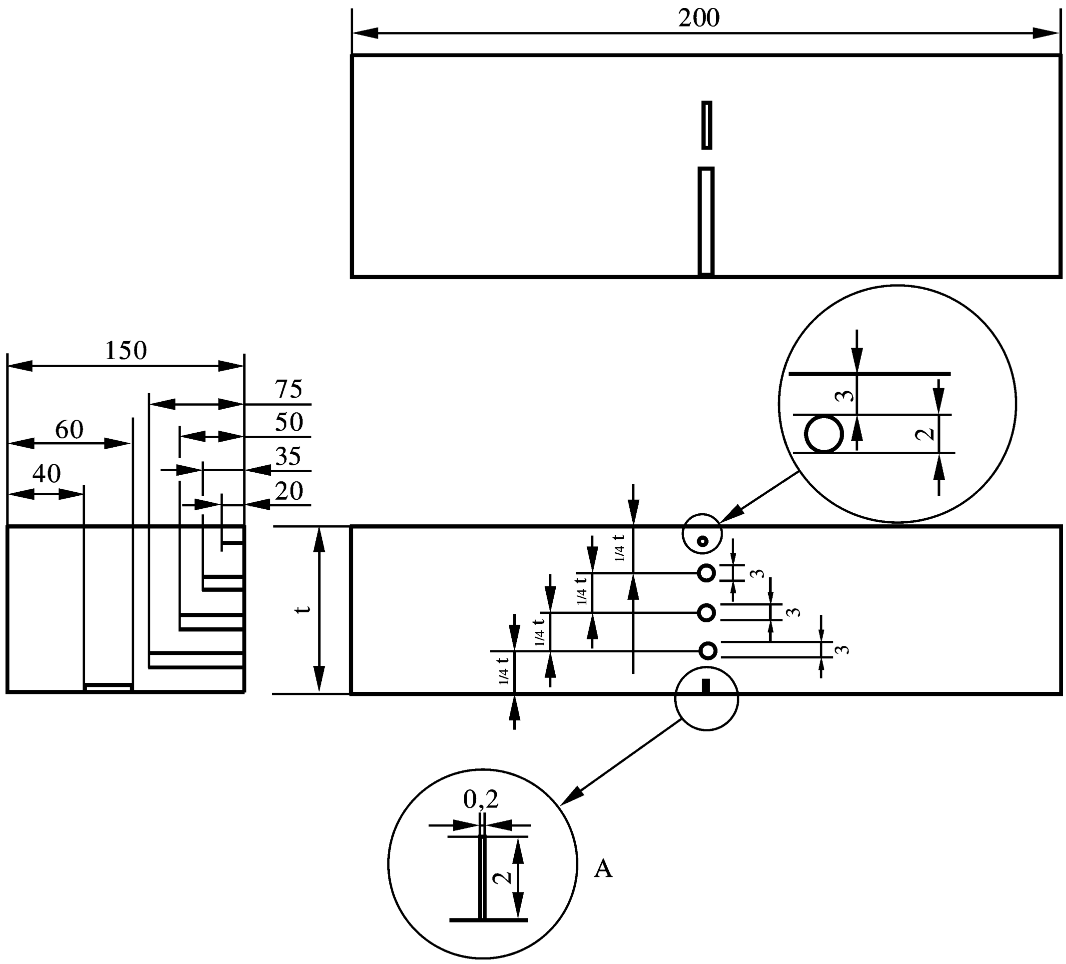


Key

W Width
L Length
T Thickness
N Notch width

Figure A.4 — Reference block containing notches

Dimensions in mm



Key

A Reference block for calibration

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

Annex B
(informative)

Examples of typical scans

B.1 Satisfactory and unsatisfactory TOFD-images

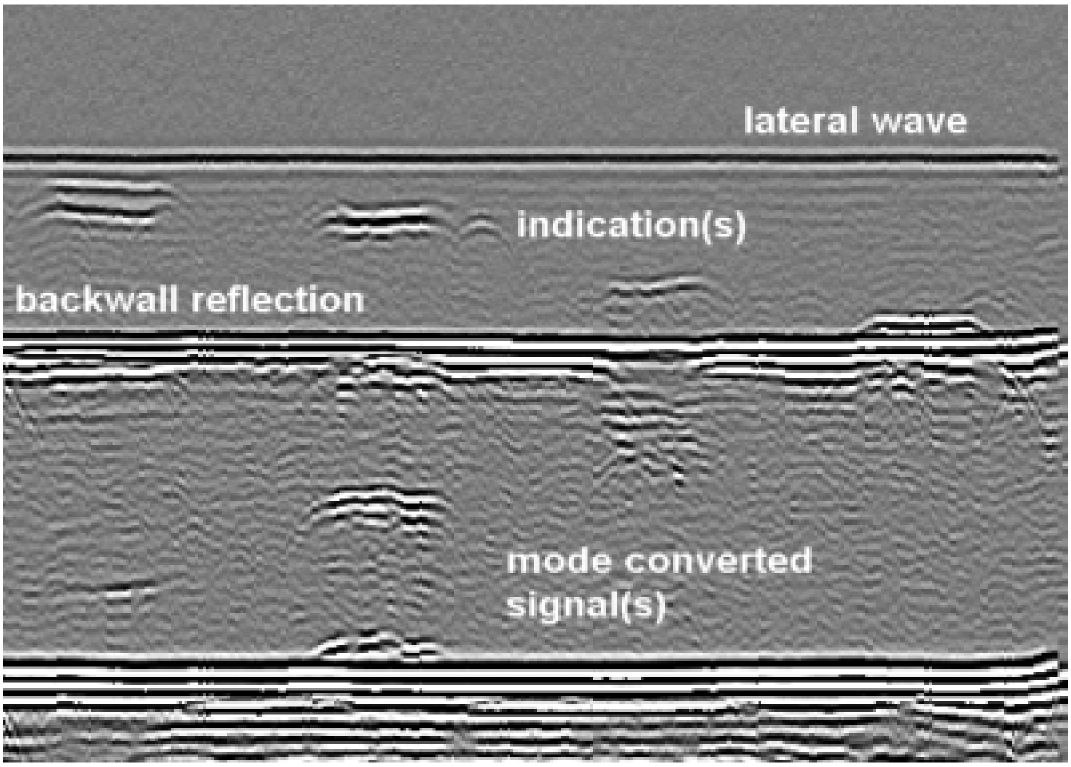


Figure B.1 — Satisfactory TOFD-image displaying

- **undisturbed lateral wave (amplitude between 40 % and 80 % FSH)**
- **four indications of notches in different depths**
- **straight backwall reflection**
- **mode converted signals from notches and backwall**

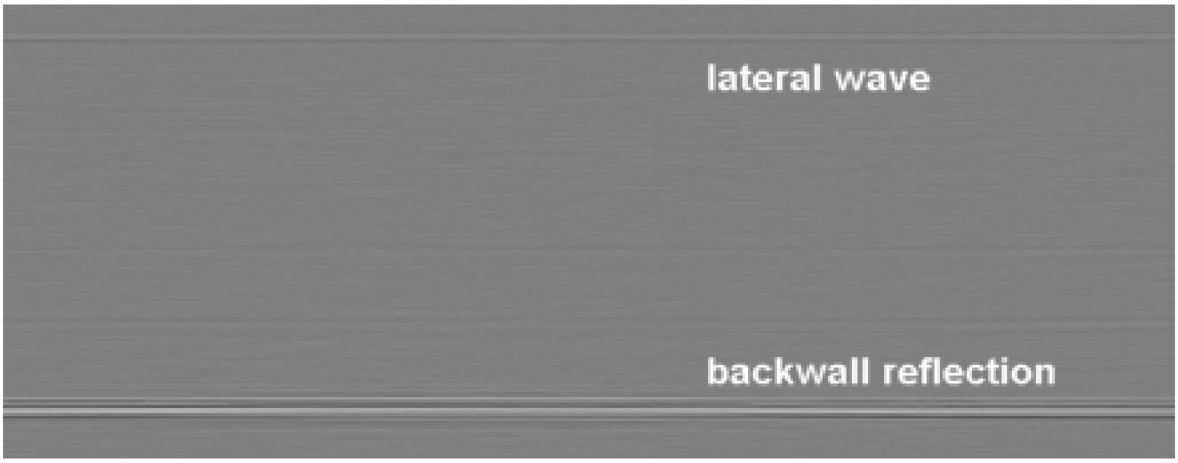


Figure B.2 — Gain setting too low
Amplitude of lateral wave << 40 % FSH

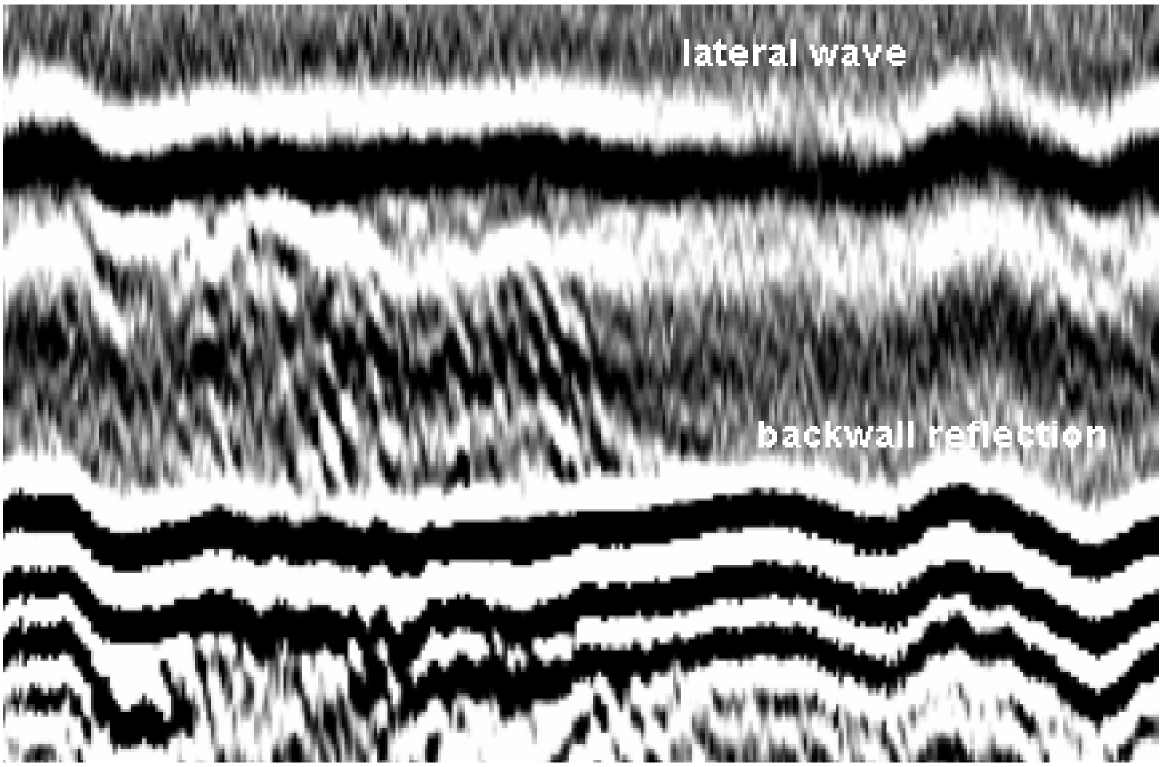


Figure B.3 — Gain setting too high
Amplitude of lateral wave >> 80 % FSH (saturated)

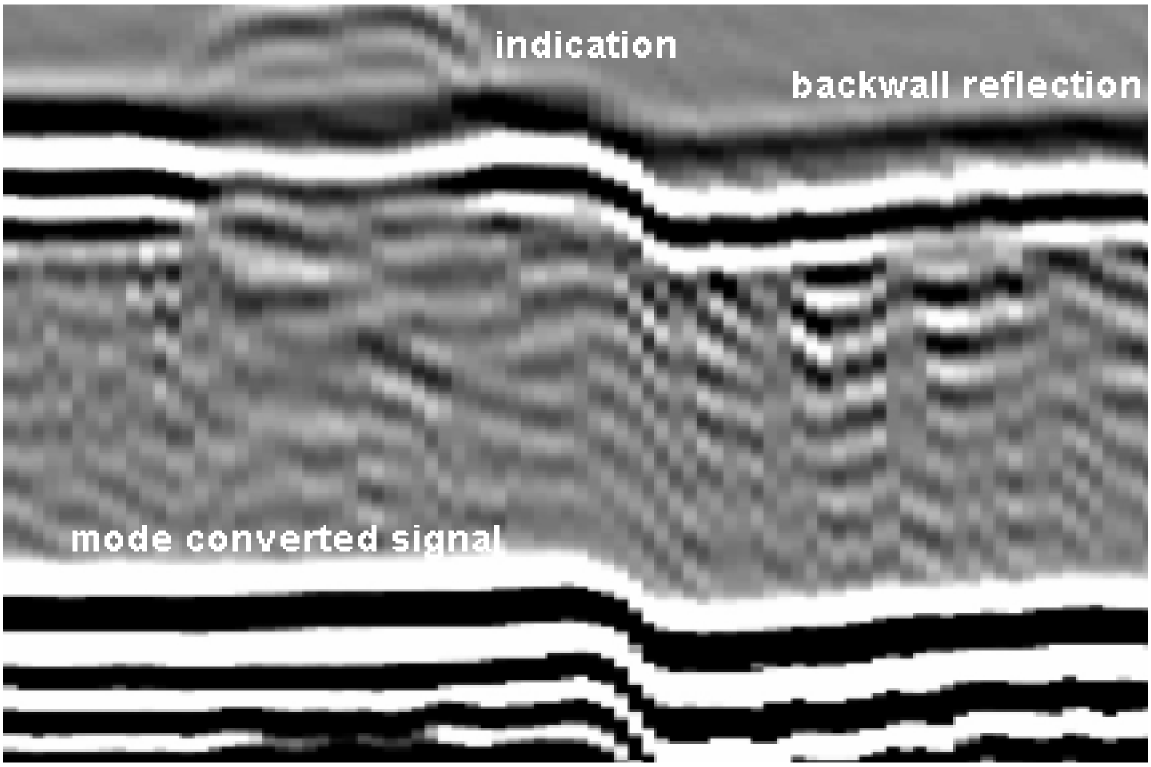


Figure B.4 — Inappropriate time window setting
Lateral wave is not present in the time window

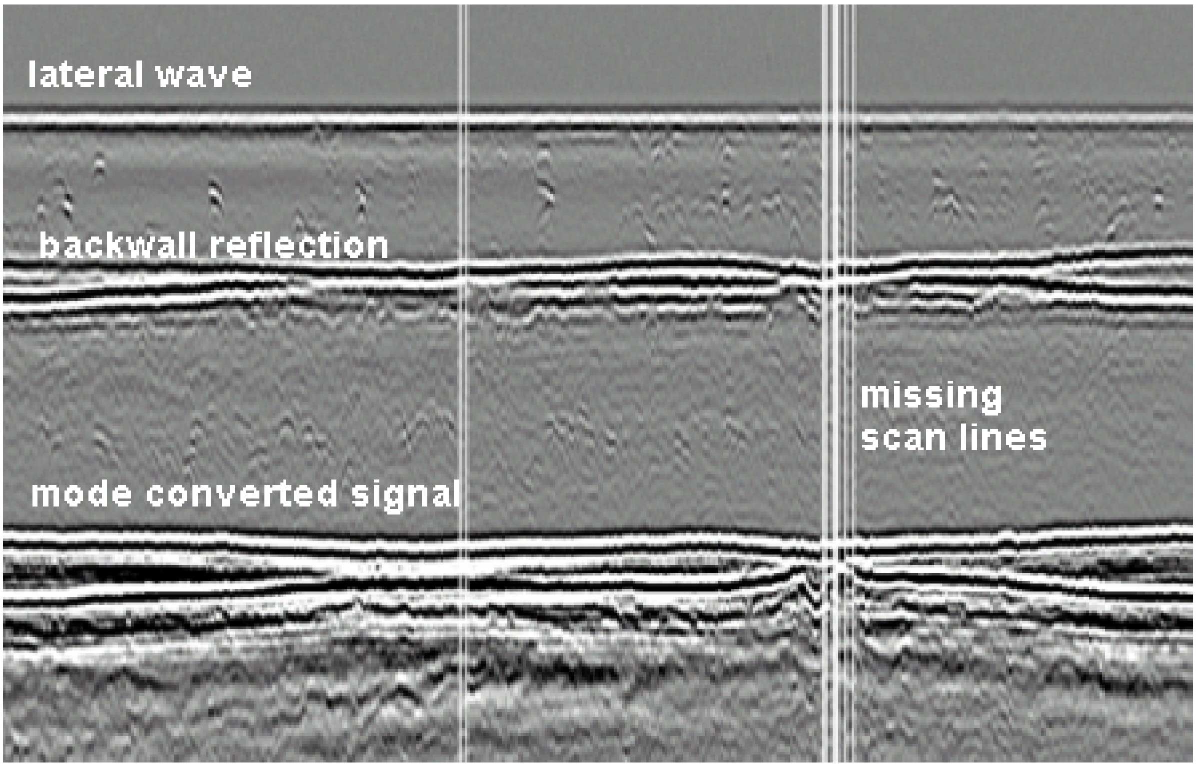


Figure B.5 — Missing scan lines caused by too high scanning speed

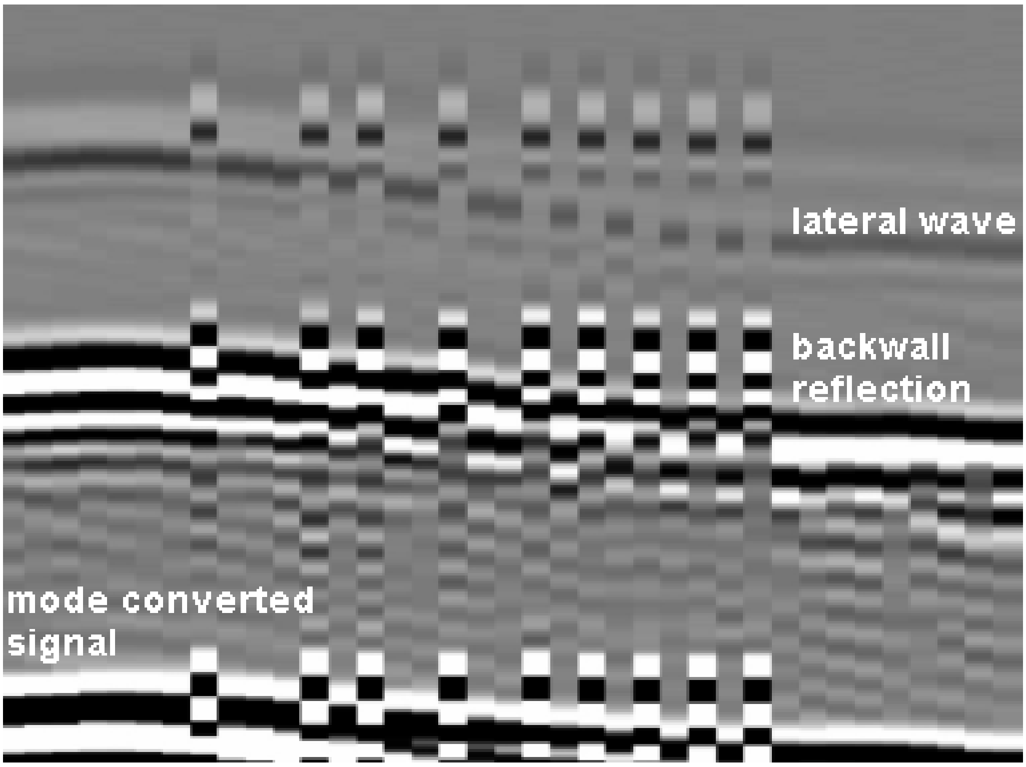


Figure B.6 — Time base triggering problems

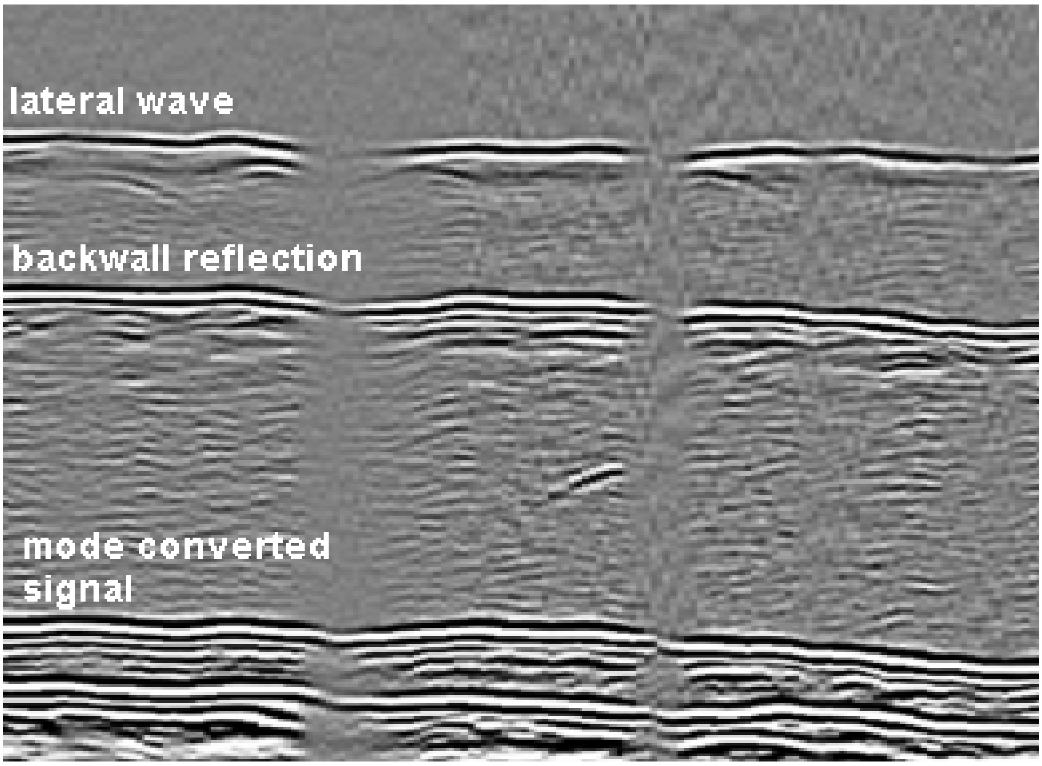


Figure B.7 — Loss of signals due to lack of couplant

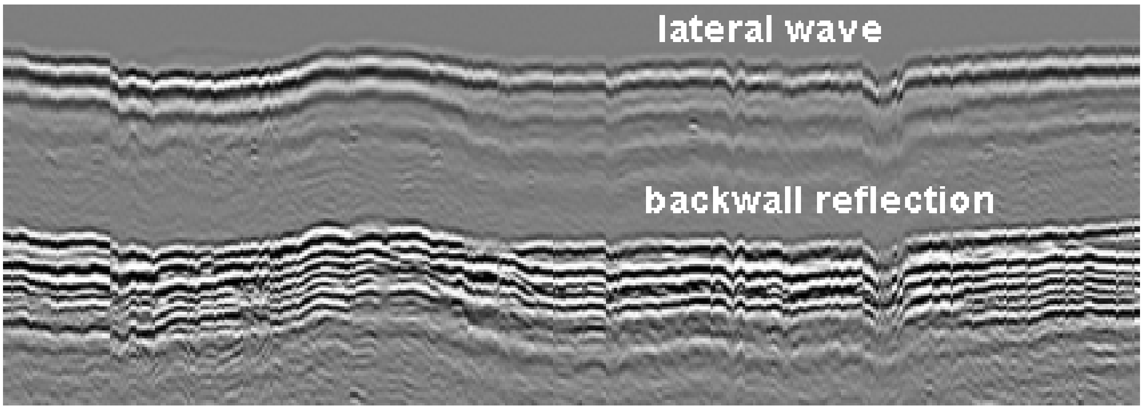


Figure B.8 — Image influenced by variation of couplant layer thickness (may be straightened by software)

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

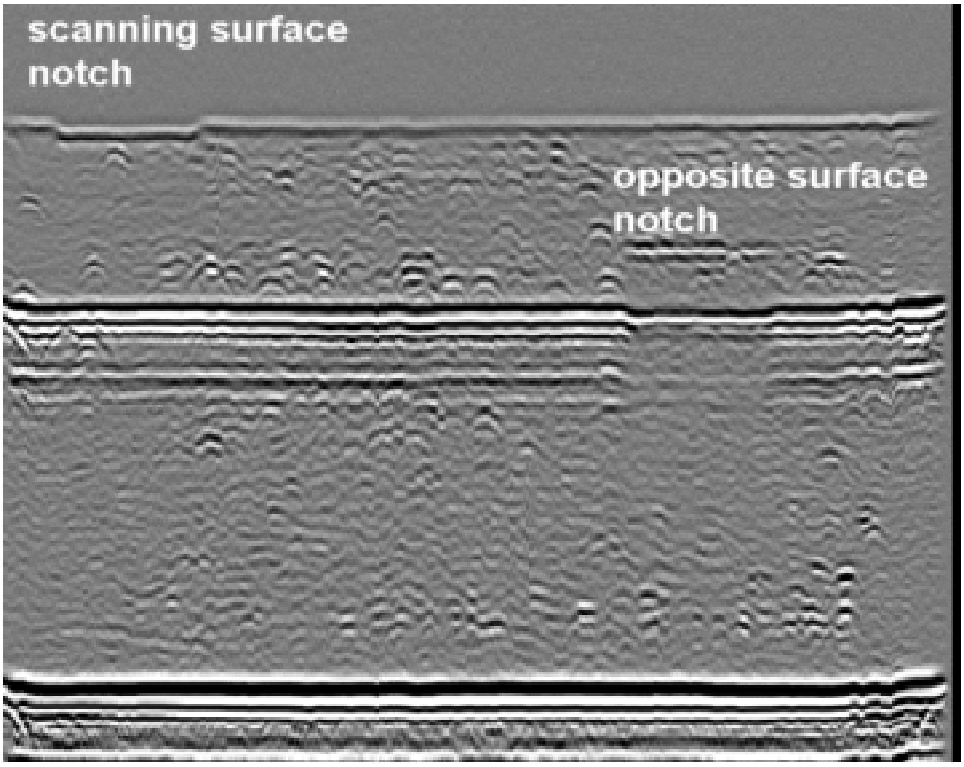


Figure B.9 — Indications of scanning surface notch (disturbance of lateral wave) and of opposite surface notch (straight diffracted signal corresponding to slight disturbance of backwall signal)

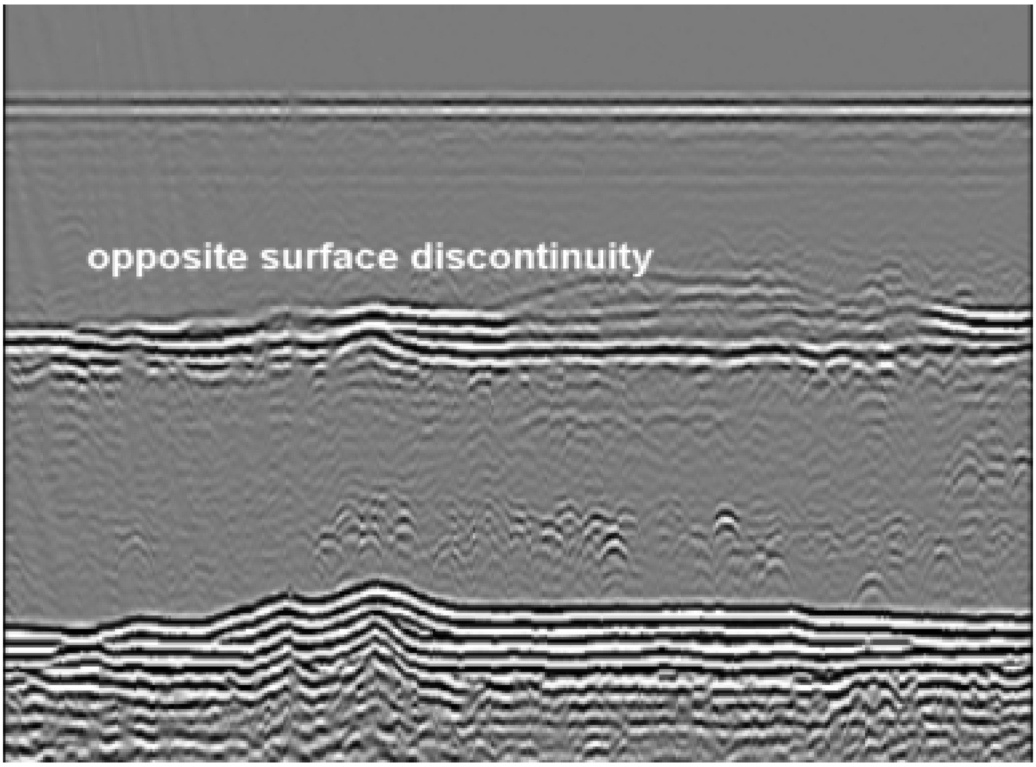


Figure B.10 — Elongated indication of an opposite surface breaking discontinuity

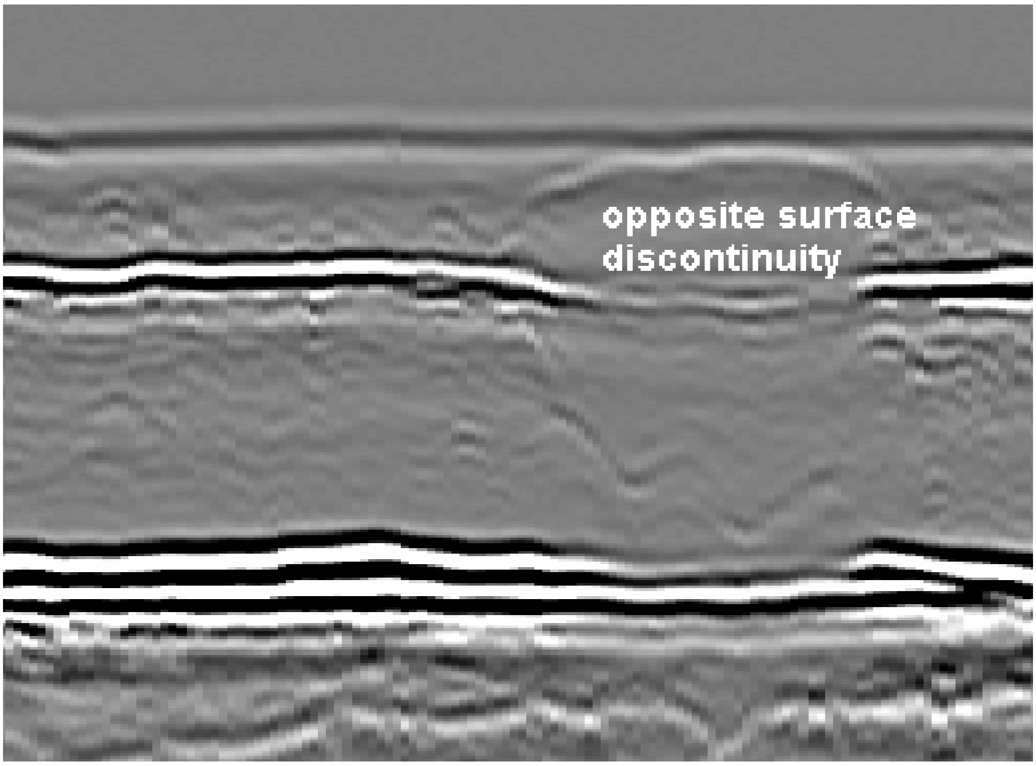


Figure B.11 — Elongated indication of a far-surface breaking discontinuity (nearly through-wall)

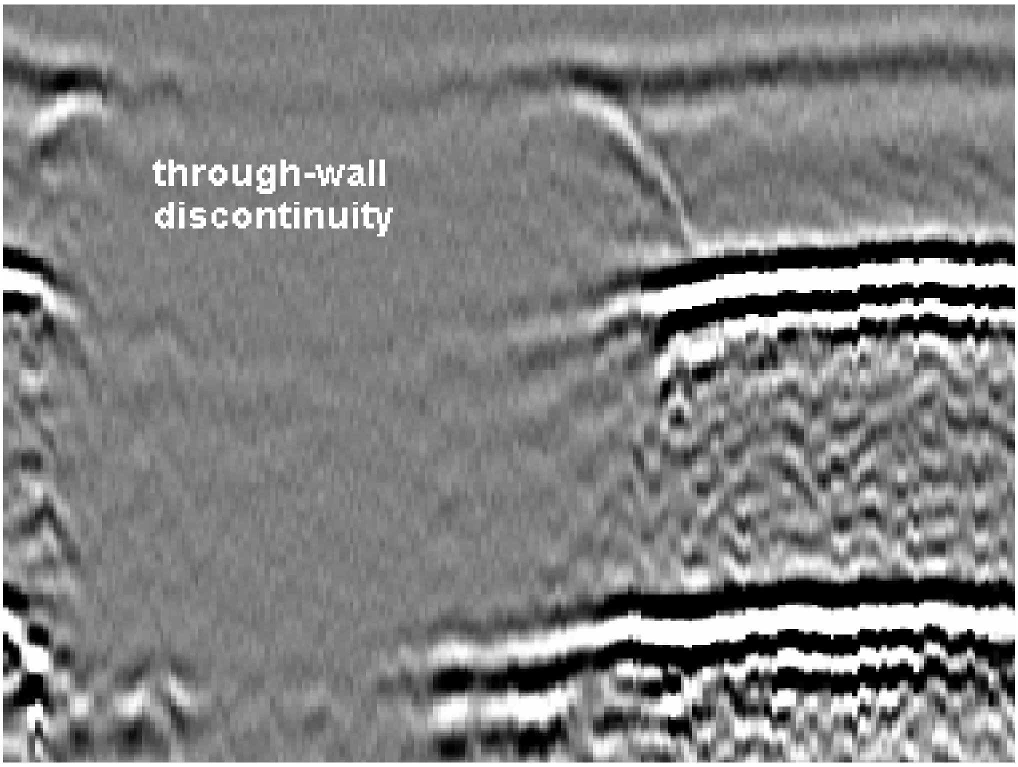


Figure B.12 — Indication of through-wall crack (note the loss of lateral wave and backwall signal and also the corresponding diffracted signal patterns left and right to this region)

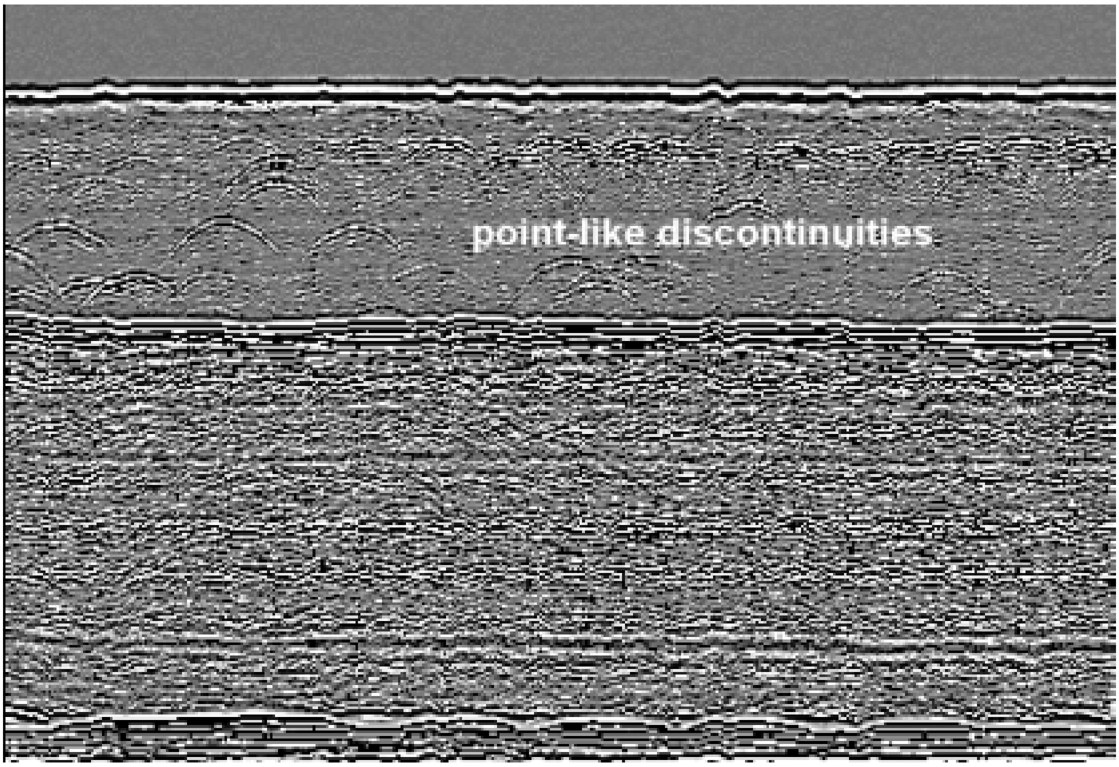


Figure B.13 — Indications of multiple point-like discontinuities

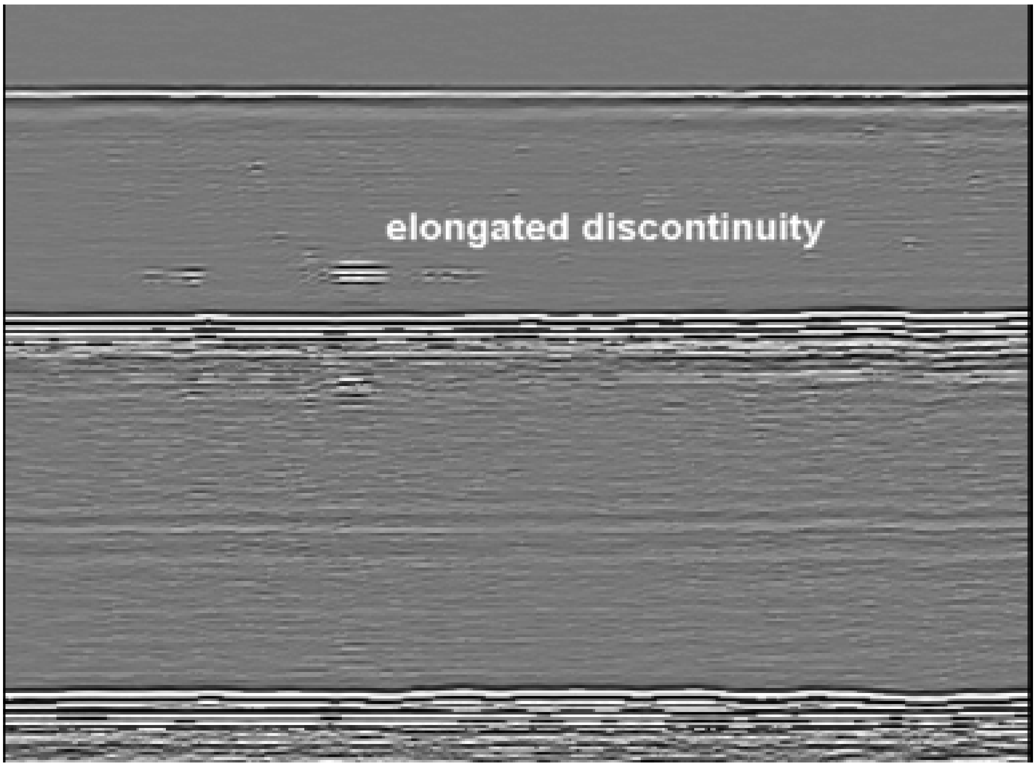


Figure B.14 — Indication of an elongated discontinuity with measurable height

B.3 TOFD-images of geometrical features

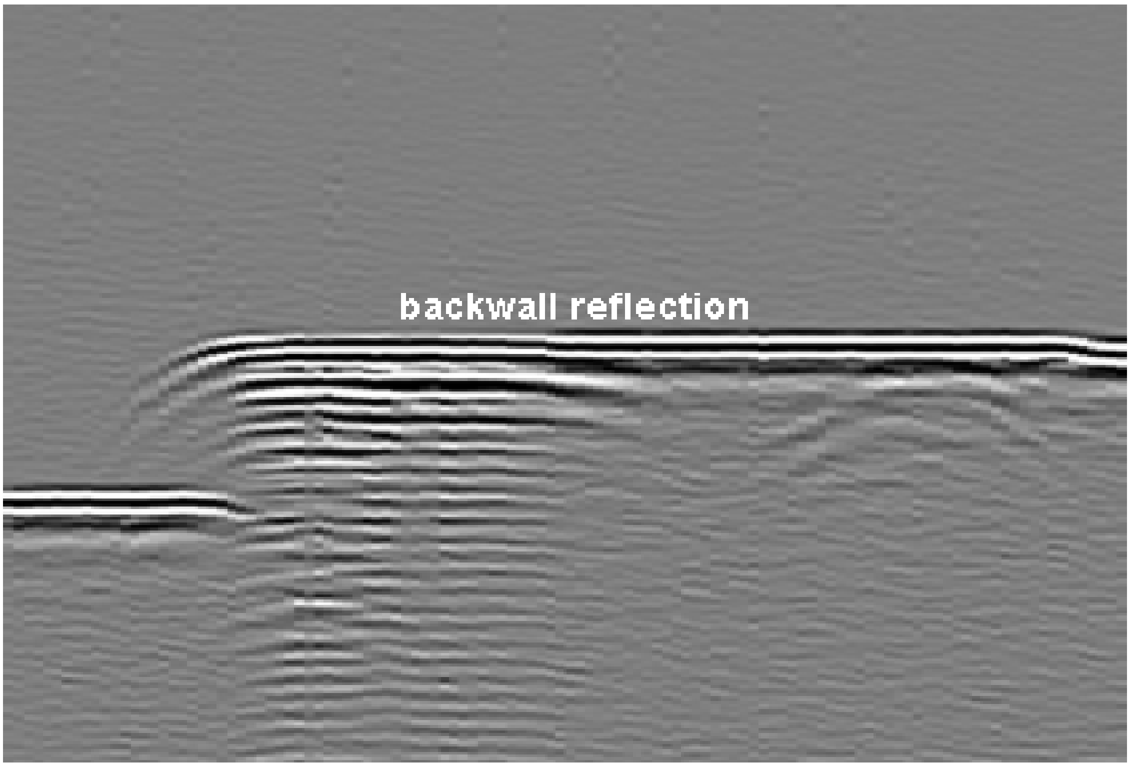


Figure B.15 — Indication of change in wall thickness

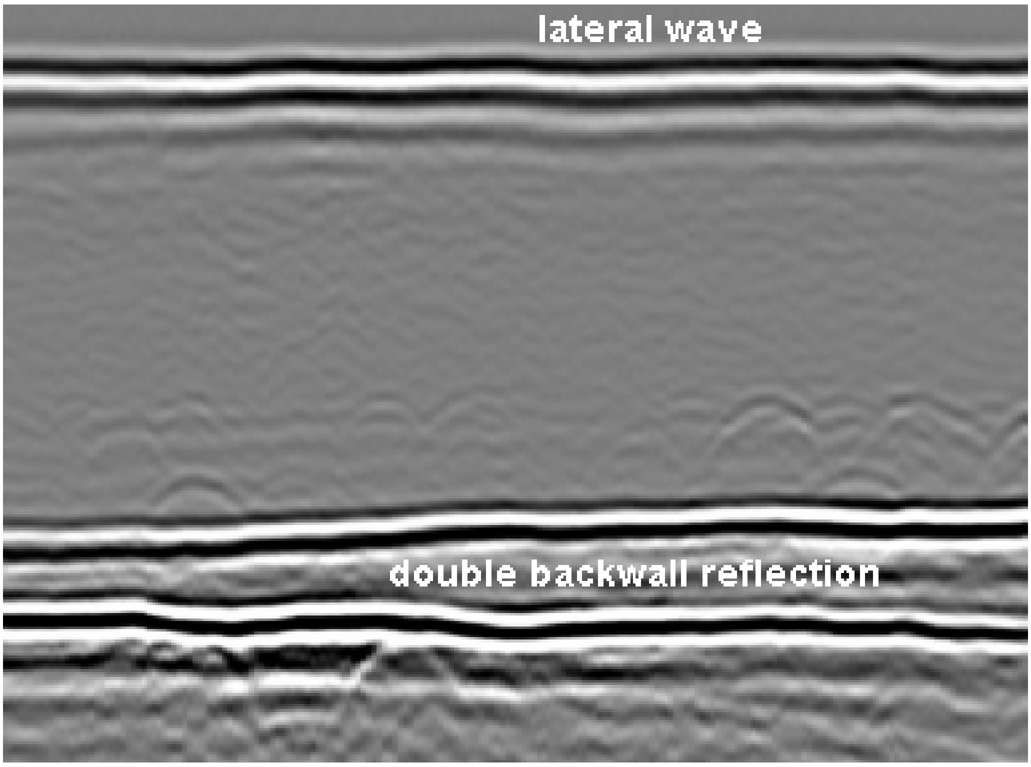


Figure B.16 — Double backwall reflection due to different wall thicknesses

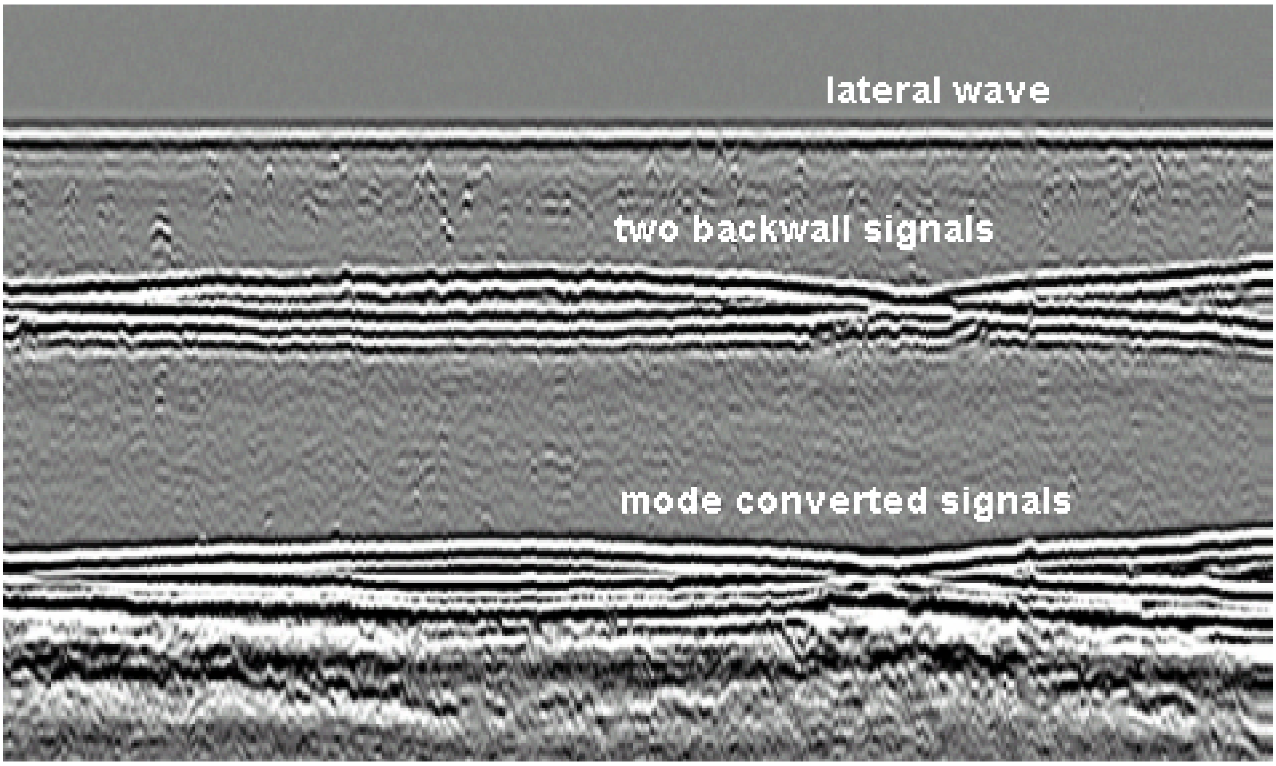


Figure B.17 — Image of misalignment in circumferentially welded pipes

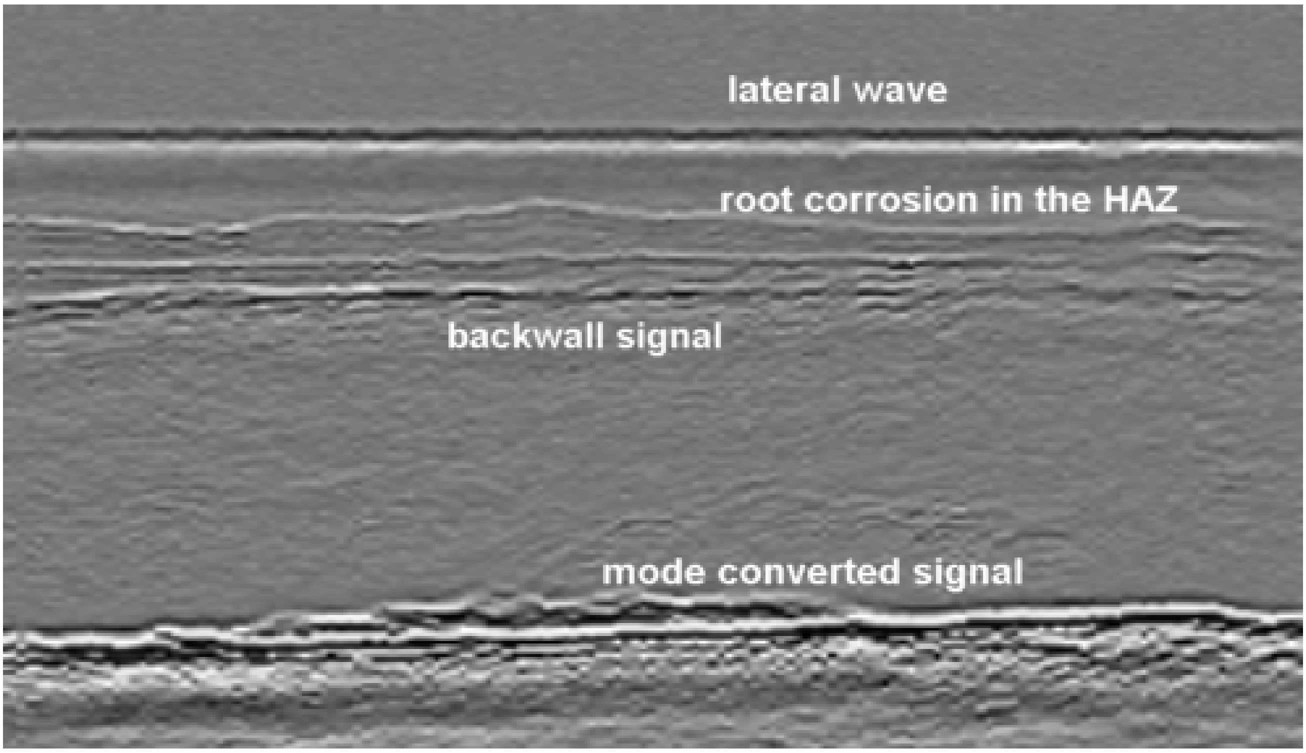


Figure B.18 — Indication of corrosion in the root-area on both sides of the weld in the heat-affected-zone (HAZ)

Bibliography

BS 7706 Calibration and setting-up of the ultrasonic time-of-flight-diffraction (TOFD) technique for the detection, location and sizing of flaws

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