International Standard

ISO 18563-3

Second edition
2024-05

Non-destructive testing — Characterization and verification of ultrasonic phased array equipment —

Part 3: **Complete systems**

Essais non destructifs - Caractérisation et vérification de l'appareillage ultrasonore multiélément —

Partie 3: Systèmes complets

Reference number
ISO 18563-3:2024(en)

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Published in Switzerland

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Foreword

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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 document 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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This document was prepared by Technical Committee ISO/TC 135 *Non-destructive testing*, Subcommittee SC 3 *Ultrasonic testing,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 138, *Non-destructive testing,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 18563-3:2015), which has been technically revised.

The main changes are as follows:

— integration of matrix array probes;

— deletion of group 1 and 2 tests;

— addition of a clause on the use of imaging for complete system verification (9.4.3) as a simplification for a more functional standard (characterisation of beams moved to Annex A);

— addition of signal processing techniques using arrays (e.g. total focusing technique (TFM)) in the scope.

A list of all parts in the ISO 18563 series can be found on the ISO website.

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.

Non-destructive testing — Characterization and verification of ultrasonic phased array equipment —

Part 3: Complete systems

1 Scope

This document addresses ultrasonic test systems implementing array probes, for contact technique (with or without wedge) or for immersion technique, with centre frequencies in the range of 0,5 MHz to 10 MHz.

This document provides methods and acceptance criteria for determining the compliance of the complete system (see 3.2). Its purpose is for the verification of the correct operation of the system prior to testing or verification of the absence of degradation of the system.

The methods are not intended to prove the suitability of the system for particular applications but are intended to prove the capability of the complete system (used for an application) to operate correctly according to the settings used. Tests can be performed on individual ultrasonic beams (for phased array technique, see 9.4.4) or on resulting images (for phased array technique and total focusing technique, see 9.4.3).

The tests can be limited to the functions that are intended to be used for a certain application.

This document does not cover the sensitivity setting of the system for a specific application. Nor does it apply to the characterization or verification of the mechanical scanning equipment. It is intended that these items will be covered by the test procedure.

This document does not address the phased array technique using tandem technique.

The characterization of beams, as recommended in case of dead elements or for more in-depth knowledge of the beams, is presented in Annex A. It is not applicable for signal processing technology using arrays.

NOTE Unless stated otherwise, in this document 'TFM' and 'TFM technique' refer to the total focusing technique as defined in ISO 23243, and to related techniques, see for example ISO 23865 and ISO 23234.

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 18563-1, *Non-destructive testing — Characterization and verification of ultrasonic phased array equipment — Part 1: Instruments*

ISO 18563-2, *Non-destructive testing — Characterization and verification of ultrasonic phased array equipment — Part 2: Probes*

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

ISO 23243, *Non-destructive testing — Ultrasonic testing with arrays — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5577, ISO 23243 and the following apply.

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

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

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

3.1
combined equipment
connected set including the instrument, the array probe (with wedge if applicable) and connecting cables, including adapters

[SOURCE: ISO 23243:2020. Modified – array and wedge added]

3.2
complete system
combined equipment including the settings for a given mode of operation

Note 1 to entry: Settings are specific values or ranges of values, e.g. electronic scanning or steering range.

3.3
reference system
complete system, including an instrument according to ISO 18563-1 and an array probe initially according to ISO 18563-2, on which all of the applicable tests defined in Clause 9 of this document have been performed successfully

3.4
identical system
complete system in which instrument, array probe, wedge, connecting cables and the settings for a given mode of operation are identical to those of the reference system

Note 1 to entry: Components are identical if from the same manufacturer and the same model.

3.5
system record sheet
document for reporting the results for a complete system which enables a comparison with the values obtained from the reference system

4 Symbols

For the purposes of this document, the symbols given in Table 1 apply.

Table 1 — Symbols

Symbol	Unit	Definitions
$(X_C; Z_C)$	mm; mm	Coordinates of the position of the centre of the reference reflector
$(X_M; Z_M)$	mm; mm	Coordinates of the position of maximum amplitude of an indication
A_{el}	V or % FSH	Amplitude of one elementary signal
a_i	mm	*Contact technique*: reduced projected sound path length *Immersion technique*: distance between the orthogonal projection of the axis of the side-drilled hole on the test surface and the centre of the probe front surface
A_{max}	V or % FSH	Maximum value of the amplitudes of all elementary signals
A_{min}	V or % FSH	Minimum value of the amplitudes of all elementary signals, excluding the dead elements
A_{ref}	V or % FSH	Median value of the amplitudes of all elementary signals

Table 1 *(continued)*

Symbol	Unit	Definitions
D	mm	Diagonal of the active aperture
D_{CM}	mm	Distance between the centre of a side-drilled hole and the point of maximum amplitude of the indication of this hole
G_{ref}	dB	Reference gain
N	mm	Near-field length associated with the active aperture
p	mm	Pitch
X_s	mm	Distance between the probe front surface and the probe index point for the studied beam
ΔS_{el}	dB	Relative sensitivity of an element
Θ	°	Angle of refraction
λ	mm	Wavelength

5 General requirements for conformity

5.1 General

All following tests shall be performed with an instrument that complies with ISO 18563-1 and an array that initially complied with ISO 18563-2.

The tests can be limited to the functions that are intended to be used for a certain application, e.g. used channels of the instrument or used part of the array or specific settings for a specified mode of operation.

When all required tests have been successfully conducted, the complete system is considered to conform to this document.

5.2 Reference system

a) The tests to be performed prior to the first use of a complete system are described in Table 4.

When all required tests have been successfully conducted, this complete system may be used as a reference system. The results of the measurements made are the base values.

b) A system record sheet of these base values shall be created.

5.3 Identical system

a) When an identical system is created, and/or when using other channels of the instrument and duplicating the settings, or after a maintenance operation or after the replacement of a system component, the tests as described in Table 4 shall be performed again.

b) The results of the measurements made on the identical system shall be recorded in the system record sheet and compared against the base values.

5.4 Periodic checks

a) For a periodic check of correct operation of the system, the tests as described in Table 4 shall be performed again.

b) The frequency of checking of the complete system shall be specified in the test procedure, e. g. before starting and at the end of the non-destructive testing or daily, weekly, monthly, depending on the application.

c) Each periodic check shall be documented on the system record sheet, either by recording the values of the checks or by stating that the results are within the acceptance criteria.

6 Qualification of test personnel

a) Personnel performing the verifications in accordance with this document shall be qualified to an appropriate level in ultrasonic testing in accordance with ISO 9712 or equivalent.

b) In addition to general knowledge of ultrasonic testing, the operators shall be familiar with, and have practical experience in, the use of the ultrasonic phased array technique or the total focusing technique (TFM).

7 Modes of operation for phased array techniques

This clause is not applicable for signal processing techniques using arrays, e.g. TFM.

This clause is applicable for phased array techniques based on beams by using a set of delay laws for multiple array elements during transmission and/or reception.

Depending on the application, the following options of the phased array technique may be used:

— number of active apertures (one or multiple);

— number of shots or delay laws (one or multiple) per active aperture;

— type of delay law (beam steering, beam focusing or combined setting).

The six most common modes of operation for phased array techniques are defined in Table 2.

Examples of modes of operation for phased array techniques are illustrated in Table 3.

Considering these different modes of operation and their resulting beams, the number of beams or images to be tested is described in Table 4.

Table 2 — Definition of modes of operation for phased array techniques

Modes	Number of active apertures	Number of delay laws per active aperture	Identical or different set of delay laws for each aperture	Array orientation	Resulting beam(s)
Mode 1	One	One	Not applicable (only one aperture)	Not relevant	One beam
Mode 2	One	Multiple	Not applicable (only one aperture)	Not relevant	Multiple beams from one active aperture
Mode 3	Multiple	One	Identical	Array parallel to the test surface	One beam from each active aperture, all beams are identical
Mode 4	Multiple	Multiple	Identical	Array parallel to the test surface	Multiple beams from each active aperture, beams are identical for all active apertures
Mode 5	Multiple	One	Identical	Array not parallel to the test surface	One beam from each active aperture, beams are different for each active aperture
			Different	Not relevant	
Mode 6	Multiple	Multiple	Identical	Array not parallel to the test surface	Multiple beams from each active aperture, beams are different for each active aperture
			Different	Not relevant	

Table 3 — Examples of modes of operation for phased array techniques

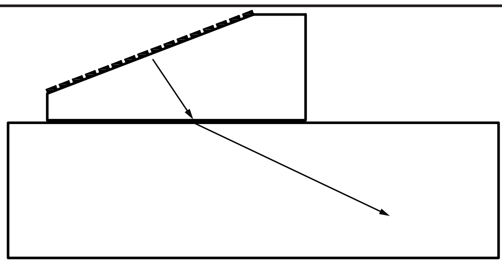
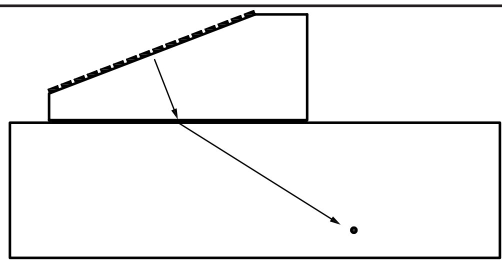
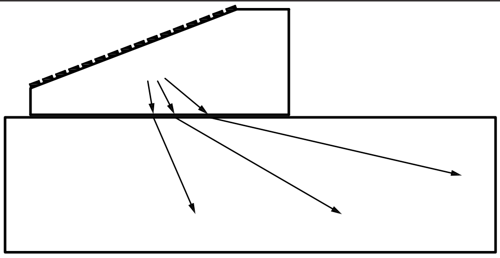
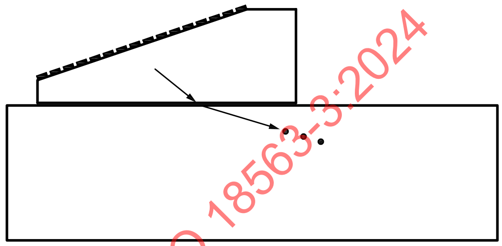
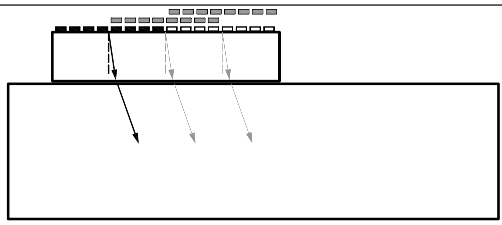
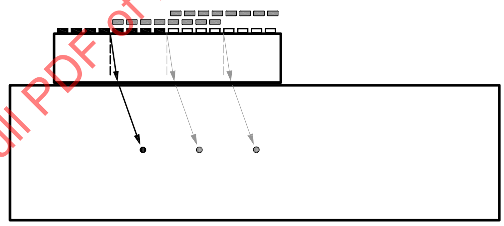
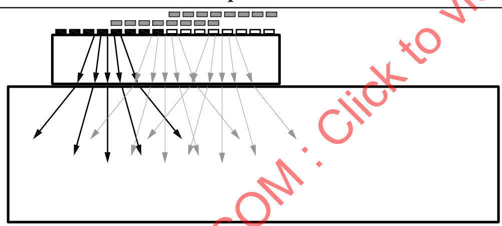
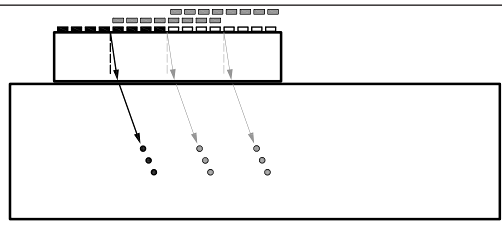
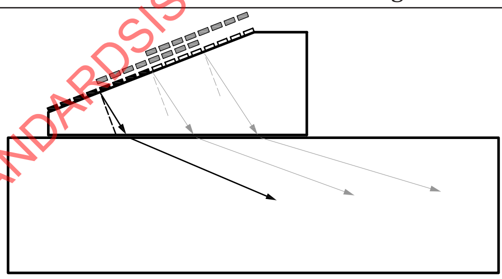
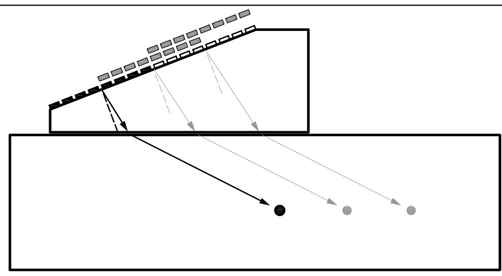
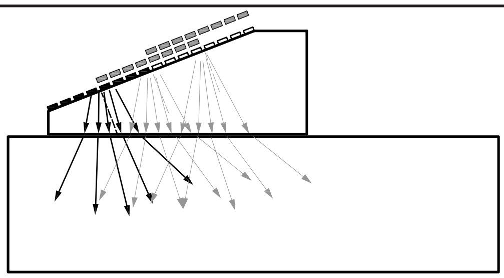
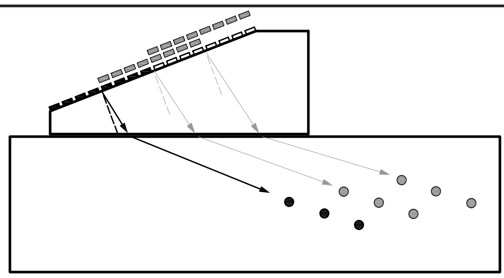
Modes	Examples	
Mode 1	 a) Beam steering	 b) Beam focusing on one point
Mode 2	 a) Electronic sectorial scanning	 b) Focusing on several points
Mode 3	 a) Electronic linear scanning with constant delay path	 b) Electronic linear scanning with focusing
Mode 4	 a) Electronic sectorial scanning together with electronic linear scanning	 b) Focusing on several points together with electronic linear scanning
Mode 5	 a) Electronic linear scanning with varying delay path	 b) Electronic linear scanning with focusing or combined electronic scanning
The medium between the array and the test object may be a fluid (immersion) or a solid (e.g. wedge). NOTE 1 For simplicity, only the beam centre lines are indicated. An arrow indicates the beam direction, dots indicate focal points.		

Table 3 *(continued)*

Modes	Examples	
Mode 6	 a) Electronic sectorial scanning together with electronic linear scanning	 b) Focusing on several points together with electronic linear scanning
The medium between the array and the test object may be a fluid (immersion) or a solid (e.g. wedge).		
NOTE 1 For simplicity, only the beam centre lines are indicated. An arrow indicates the beam direction, dots indicate focal points.		

8 Equipment required for tests

The equipment required for the tests of a complete system includes:

a) suitable reference block(s);

b) measurement devices for the length with an accuracy of ±0,5 mm and for the angle with an accuracy of ±1°.

9 Tests to be performed

9.1 General

a) Before performing the tests, the equipment settings shall be made according to the array and wedge that are in use for the application.

b) For applications where only a part of the array is used, the tests can be limited to this part. In that case, the results of the tested part of the array shall be recorded on the system record sheet, including a description of the tested part of the array.

c) The tests described in Table 4 shall be performed initially (5.2), after every maintenance operation or after the replacement of a system component (5.3), and periodically (5.4).

Table 4 describes the various tests to be conducted on a complete system based on the different modes of operation for phased array techniques.

The last column of Table 4 describes the various tests to be conducted on a complete system in case of signal processing techniques using arrays. For conciseness, it is named TFM mode.

For tests where Table 4 indicates that it is required to verify at least three beams, apertures or presentations, this means at least the median and both extreme situations shall be verified.

For phased array technique, tests can be performed either on individual ultrasonic beams or on resulting images, if applicable.

For total focusing technique, tests can only be performed on resulting images, because no individual ultrasonic beams are available.

Table 4 — Tests to be performed

Items	Test and clause	Mode 1	Mode 2 Example a	Mode 2 Example b	Mode 3	Mode 4	Mode 5	Mode 6	TFM mode
External aspects	External aspects of the equipment 9.2	Required							
Elements and channels	Channel assignment 9.3.2	Required for used channels							
	Relative sensitivity of elements, reference amplitude and dead elements 9.3.3	Required for used channels							
Correct operation [c]	Amplification system 9.4.2	Required for used channels							
	Using imaging [a] 9.4.3	Not applicable	S-scan presentation	Not applicable	L-scan presentation	At least one L-scan or S-scan presentation	L-scan or S-scan presentation	At least three L-scan or S-scan presentations [b]	TFM image
	Using beams [a] 9.4.4	Used beam	At least 3 beams [b]		At least three apertures [b]	At least the three following beams: first shot of first aperture, last shot of last aperture and median shot of median aperture	At least three apertures [b]	At least three apertures [b], and three beams [b] for each of these apertures	Not applicable
	Skew angle 9.4.5								Required if applied
	Characterization of sound beams Annex A	Optional							Not applicable
Other verifications	Squint angle 9.5.1	Required							
	Grating lobes 9.5.2	Optional							

[a] Verification of correct operation is either done by using imaging (9.4.3) or by using beams (9.4.4).

[b] Verifications shall be done for extreme and median beams or apertures or presentations.

[c] For matrix array probes generating beams with skew angles, the verifications shall be performed in the extreme and median deflection planes.

9.2 External aspects of the equipment

9.2.1 General

This general visual inspection is intended to verify that there is no degradation of the test equipment.

9.2.2 Procedure

a) Visually inspect the outside of the ultrasonic instrument, the array probes, the cables and the connectors in order to detect any sign of damage or wear that can affect both the current operation of the system and its long-term reliability.

b) In particular, inspect the contact surface of the array probe and the wedge.

c) If the probe is made out of various components, verify that they are correctly assembled.

d) Check the wedge dimensions by measuring with a ruler to detect any wear.

9.2.3 Acceptance criteria

All the components of the system shall not show any visible sign of damage or wear that influences the beam characteristics or imaging.

9.2.4 Reporting

The results of the visual inspection shall be recorded on or appended to the system record sheet.

9.3 Elements and channels

9.3.1 General

These tests are to ensure proper connection of the array probe to the instrument and correct operation of the array probe once connected.

The tests address:

a) the verification of channel/element assignment for transmission and reception, and the capability of the instrument to perform the electronic switching operations necessary to activate individual elements successively;

b) the measurement of the relative sensitivity of the array elements, and the reference amplitude;

c) the identification of any failing component (e.g. dead elements).

9.3.2 Channel assignment

9.3.2.1 Procedure

a) Use a test block with a planar reflecting surface that is not parallel to the array in order to generate increasing time-of-flight values from element to element, see Table 5 and Figure 1.

b) Activate the elements one by one from the first element to the last element of the array.

c) Compare the individual time-of-flight values of the signals from the reflecting surface from element to element (e.g. by A-scans, L-scans) (Figure 2).

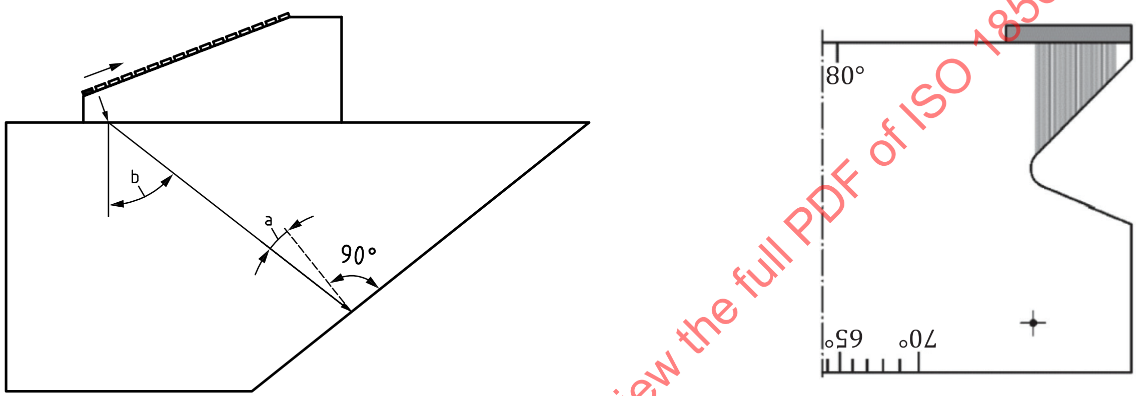
d) The verification for matrix array probes shall be performed in two phases:

   1) first check the individual elements column by column;

2) then, having rotated the matrix array probe by 90°, or a small skew angle when using a wedge, check row by row.

Table 5 — Test blocks to be used depending on the configuration

Technique	Probe configuration	Reflecting surface
Contact technique	Without wedge (or wedge removed)	Block with planar surfaces that are non-parallel (Figure 1 b))
	With a wedge	Wedge contact surface if the time-of-flight values differ from element to element or Block with a planar reflecting surface where the impingement angle of the natural refracted beam is at least a few degrees (Figure 1 a))
Immersion technique	-	Block with a planar reflective test surface tilted by at least a few degrees with respect to the probe



a) For an array with wedge

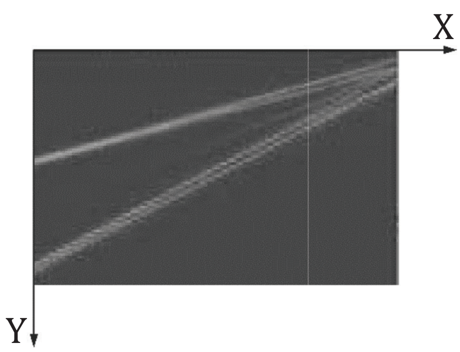
b) For an array without wedge on a block, e.g. according to ISO 19675

Key

a impingement angle of the natural refracted beam

b natural refracted beam angle

Figure 1 — Verification of channel assignment



Key

X element position.

Y time of flight.

Figure 2 — Comparing elementary time of flight on imaging, e.g. L-scan

9.3.2.2 Acceptance criteria

a) The longest time of flight shall be associated with the element farthest from the reflecting surface;

b) The shortest time of flight shall be associated with the element closest to the reflecting surface;

c) The time of flight of the received signals shall vary monotonically with element position.

9.3.2.3 Reporting

The settings and results of the test shall be recorded on or appended to the system record sheet.

9.3.3 Relative sensitivity of elements, reference amplitude and dead elements

9.3.3.1 General

The objectives of the following tests are to check the relative sensitivity of the elements, to identify dead elements and to determine the reference amplitude.

An additional objective of periodic tests is to verify that the possible occurrence of changes in the relative sensitivity of the elements has no influence on the correct operation of the system.

9.3.3.2 Elementary sensitivity

9.3.3.2.1 Procedure for contact technique

a) Position the array probe on a test block in order to obtain the same time of flight for all of the elements, e.g.:

   1) preferably without a wedge (if possible), using a block with parallel surfaces;

   2) with a delay line, using the signals from the delay line contact surface;

   3) with a wedge, using a test block of the same material with one side inclined at the same angle as the probe wedge;

b) Activate the elements one by one (transmit and receive with the same element).

c) Display the amplitude of the echo from the reflector for each element.

d) Adjust the gain to have the signal amplitudes approximately at 80 % of FSH and, if necessary, reduce the gain if the maximum amplitude cannot be read from the display (above 100 % of FSH).

e) Measure the amplitude A_{el} of each elementary signal in % of FSH.

f) For dual-array probes, perform tests a) to e) for each array separately.

   In case of a non-removable wedge, use an adapted block that compensates for the influence of the roof angle.

9.3.3.2.2 Procedure for immersion technique

a) Position the array probe parallel to an immersed test block in order to obtain the same time-of-flight values for all of the elements.

b) Activate the elements one by one (transmit and receive with the same element).

c) Display the amplitude of the interface echo for each element; perpendicular incidence is obtained if all signals show an equivalent time of flight within a half-period tolerance.

d) Adjust the gain to have the signal amplitudes approximately at 80 % of FSH and, if necessary, reduce the gain if the maximum amplitude cannot be read from the display (above 100 % of FSH).

e) Measure the amplitude A_{el} of each elementary signal in % of FSH.

9.3.3.3 Determination of the reference amplitude

The reference amplitude A_{ref} is defined as the median of the elementary amplitudes of the elements A_{el}.

a) Calculate A_{ref} and record it on the system record sheet, together with the applied gain.

b) During the system's service life, use the same settings and the same test block, recalculate A_{ref} every time to check the absolute sensitivity of the system.

9.3.3.4 Identification of dead elements

Calculate the relative sensitivity ΔS_{el} (in dB) of each element using Formula (1):

$$\Delta S_{el} = 20\log(A_{el}/A_{ref}) \quad (1)$$

An element is considered a dead element, if $\Delta S_{el} < -9$ dB.

A loss of sensitivity can be caused by the array element, the cable and/or the instrument.

Regardless of the reason, this is named a dead element.

9.3.3.5 Range of sensitivity of elements

A_{max} is defined as the maximum A_{el} value.

A_{min} is defined as the minimum A_{el} value excluding dead elements.

Check the range of sensitivity of elements by comparing A_{min} and A_{max}.

9.3.3.6 Acceptance criteria

The following criteria shall be applied:

a) The reference amplitude A_{ref} is acceptable if the signal-to-noise ratio is acceptable for the application.

b) If the reference amplitude and the signal-to-noise ratio do not remain acceptable, the beams or images resulting from the affected active apertures shall be checked. This verification may be performed via simulation or, for phased array technique, by measurements according to Annex A.

c) The relative sensitivity of elements is acceptable if $A_{max} - A_{min} < 50$ % of FSH;

d) The maximum number of dead elements for each active aperture shall not be more than the values given in Table 6.

Table 6 — Maximum number of dead elements

Type of array probe	$0,5 < f \leq 5$ MHz	$5 < f \leq 10$ MHz
Linear array	1 out of 16	
Matrix array with number ≤ 64 elements		
Matrix array with number > 64 elements	10 %	15 %

e) For linear array probes, the dead elements shall not be adjacent.

f) For matrix array probes with up to 64 elements, the dead elements shall not be adjacent.

g) For matrix array probes with more than 64 elements, each dead element shall have maximum one adjacent dead element.

h) If new dead elements are found during periodical tests, it should be verified that the reference amplitude of the affected active apertures and the signal-to-noise ratio remain acceptable for the application.

9.3.3.7 Reporting

The settings and results of the tests shall be recorded on or appended to the system record sheet.

9.4 Verification of correct operation

9.4.1 General

a) For phased array techniques, the beams generated in the deflection plane(s) shall be verified either by using imaging (9.4.3) or by measuring the angle of refraction and the index point (9.4.4).

b) For signal processing techniques using arrays, the term beam is not relevant. Then, only the resulting TFM image in the deflection plane(s) shall be verified (9.4.3).

c) For imaging with indirect beams or indirect imaging paths, i.e. using reflection(s) at surface(s) of the test object, the verifications shall be performed using reference block(s) of known thickness.

d) In all cases, prior to the verifications described in 9.4.3 and 9.4.4, the absence of saturation of signals and the linearity of the amplification system shall be verified (9.4.2).

e) For matrix array probes operating with skew angles, the skew angles shall be verified (9.4.5).

NOTE Presentations in other planes (e.g. type C, top-view, side-view) or imaging using reflection are related to the test procedure and verifications will be described in it.

9.4.2 Amplification system

9.4.2.1 General

Ultrasonic testing is often based on the evaluation of amplitude values that can be quantitatively altered by a default in the amplification system due to either:

— a saturation of elementary signals;

— a saturation of summed signals;

— a non-linearity of the amplification system.

Summed signals are obtained either by delaying and summing elementary signals (summed A-scan for phased array technique) or by synthetic focusing by coherent summation of elementary signal amplitudes (summed amplitudes for TFM technique). Then the summed signals are displayed as summed A-scan presentations (for phased array technique) or in an image (for phased array technique or TFM technique).

The summation of multiple elementary signals may be performed analogue or digital, depending on the design of the instrument (AD-converter, amplifier, processing):

— In all cases, for phased array instruments and TFM instruments, there is a risk for saturation of summed signals, especially in case of high gain setting, strong ultrasonic signals (e.g. large reflectors) or summation over a large number of channels;

— In case all or most elementary signals are saturated, the linearity of the summed signals will deviate;

— In case only one or a few elementary signals are saturated (e.g. 1 out of 16), the linearity of the summed signals may be acceptable because of the limited influence of the saturated signals (e.g. 1/16). The influence can be so small that there is no measurable effect on the linearity of the summed signals and the system meets the acceptance criteria.

Typically, the elementary signals are not available to the operator, so the operator cannot perform a verification of elementary signals. Then the linearity of the amplification system can only be verified simultaneously with the displayed summed signals.

The following subclauses describe the procedures for verification of absence of saturation of signals and linearity of the amplification system:

a) The verifications shall be performed on the presentations and with the settings (including sensitivity on a relevant reference reflector) that are to be used in the actual testing of objects, by using:

   1) The echo height displayed in an A-scan presentation.

   2) The amplitude value displayed in an image, selected with a cursor or a box.

   3) The echo height measured in a gate, displayed as a numerical value.

b) If available on the instrument, the indication function for the absence of saturation of elementary signals shall be used (9.4.2.2).

c) Depending on the maximum summed signal amplitude value that can be displayed by the instrument:

   1) If the maximum summed signal amplitude value is 100 % of the full screen height (FSH), the vertical linearity shall be verified according to 9.4.2.3.1.

   2) If the maximum summed signal amplitude value is higher than 100 % of FSH, e.g. displayed as a value, the vertical linearity shall be verified up to this maximum amplitude value according to 9.4.2.3.2.

   3) The verification of summed signals shall also be performed in case the instrument indicates that the elementary signals are not saturated.

In case no absolute amplitude values are used in the evaluation of test objects, it is still recommended to verify the correct operation of the amplification system.

9.4.2.2 Absence of saturation of elementary signals

Phased array instruments and TFM instruments can have an indication function for saturation of elementary signals.

If saturation of elementary signals is indicated, the operator shall take appropriate measures.

9.4.2.3 Absence of saturation of summed signals and linearity of the amplification system

9.4.2.3.1 Procedure for verification of linearity up to 100 % of FSH

For presentations with a maximum summed signal amplitude value of 100 % of full screen height (FSH):

a) Apply the settings that are to be used in the actual testing of objects (including sensitivity), set and note the transmitter voltage.

b) Position the probe to visualize the echo from the reflector considered.

   The reflector to be used for this test shall be the same as the reflectors used in 9.4.3.2 and 9.4.4.2.

c) Adjust the gain so that the summed signal corresponds to 80 % of the full screen height (FSH).

d) Note the value of the calibrated gain control (dB).

e) Then increase the gain by 2 dB and confirm that the signal rises to approximately 100 % of FSH.

f) Retrieve the initial value of gain and then decrease it by 6 dB and then by an additional 6 dB.

g) Confirm that the signal drops to approximately 40 % then to 20 % of FSH according to Table 7.

9.4.2.3.2 Procedure for verification of linearity above 100 % of FSH

For presentations with a maximum summed signal amplitude value higher than 100 % of full screen height (FSH), e.g. displayed as a value when gates or images are used, the linearity of the displayed amplitude shall be verified up to the maximum amplitude value, i.e. above 100 % of FSH:

a) Apply the settings that are to be used in the actual testing of objects (including sensitivity), set and note the transmitter voltage.

b) Position the probe to visualize the echo from the reflector considered.

The reflector to be used for this test shall be the same as the reflectors used in 9.4.3.2 and 9.4.4.2.

c) Adjust the gain so that the summed signal corresponds to 80 % of the maximum possible amplitude value of the used presentation.

d) Note the value of the calibrated gain control (dB).

e) Then increase the gain by 2 dB and confirm that the signal rises to approximately 100 % of the maximum possible amplitude value of the used presentation.

f) Retrieve the initial value of gain and then decrease the gain in steps of 6 dB.

g) Confirm that the signal amplitude falls to approximately the expected amplitude value according to Table 8.

9.4.2.4 Acceptance criteria

a) If the instrument has an indication function for saturation of elementary signals, the indication function for saturation of elementary signals shall have given no warning.

b) The linearity of the summed signals in presentations up to 100 % of FSH shall comply with Table 7.

c) The linearity of the summed signals in presentations above 100 % of FSH shall comply with Table 8.

d) If the criteria are not met, a solution may be to decrease the transmitter voltage.

Table 7 — Acceptance criteria for the linearity of summed signals up to 100 % of FSH

Gain setting (dB)	**Expected amplitude** (% of full screen height)	**Limits** (% of full screen height)
+ 2	101	Not less than 95
0	80	(Reference value)
− 6	40	37 to 43
− 12	20	17 to 23

Table 8 — Acceptance criteria for the linearity of summed signals above 100 % of FSH

Gain setting (dB)	**Expected amplitude value** (% of maximum value)	**Limits** (% of maximum value)
+ 2	101	Not less than 95
0	80	(Reference value)
− 6	40	37 to 43
− 12	20	17 to 23
- 18	10	8 to 12

9.4.3 Verification of correct operation by using imaging

9.4.3.1 General

Phased array and TFM systems offer the possibility to visualize acquisition data on reconstructed 2D images in the deflection plane (e.g. L-scan presentations, S-scan presentations, TFM images), except for mode 1 and mode 2 example b.

Other presentations can also be available which are not in the deflection plane (e.g. C-scan presentation, top view, side view). All these presentations are generated through algorithms specific to the instrument assessed. These algorithms are not intended to be checked in this document.

The imaging is used to verify the correct operation of the complete system according to the settings applied, including position of the index point, angle of refraction for phased array techniques or probe position and TFM settings for signal processing techniques.

The test compares the position of indications displayed in the 2D ultrasonic image in the deflection plane with the actual position of side-drilled holes at different depths and distances in the reference block.

The verification by using imaging requires enough shots to produce a usable 2D image.

a) The test shall be performed on a reference block with side-drilled holes of 3 mm diameter at different depths.

   1) For a planar test surface, a test block according to ISO 19675 may be used.

   2) For a 0°- electronic linear scanning, the side-drilled holes shall not be vertically aligned.

   3) If a shaped wedge is used, the test block shall be adapted accordingly and have at least two side-drilled holes at different depths.

b) For matrix array probes generating beams with skew angles, the verification by using imaging shall be performed in the extreme and median deflection planes by optimising the probe direction on a reference block with side-drilled holes (9.4.5).

9.4.3.2 Procedure

9.4.3.2.1 General

For each selected mode of operation for phased array technique, or TFM mode:

a) Set the instrument according to the sound velocity of the reference block.

b) Position the probe on the reference block to display the indications of at least two reference reflectors located at different depths and distances in the 2D ultrasonic image.

   NOTE The different depths and projected distances can be achieved with different probe positions.

c) Adjust the probe position to optimise the indications in terms of amplitude and position in the image.

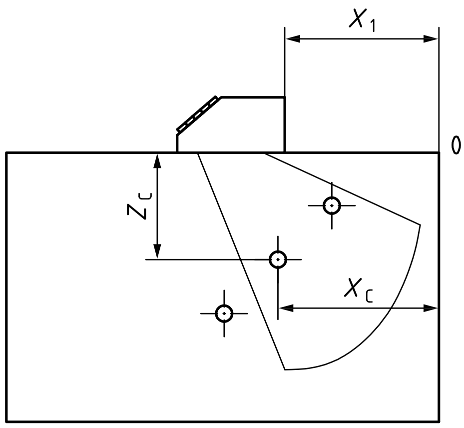
   It is necessary to display the maximum unsaturated amplitude for indications that are far enough away from the edges of the image.

d) Measure the position X_1 of the front face of the probe using a ruler to a reference point, e.g. the corner of the test block (Figure 3).

e) Set this position X_1 in the instrument (often called index offset).

f) For matrix array probes generating beams with skew angles, repeat steps b) to e) by maximising the amplitude of indications at extreme and median deflection planes by optimising the probe direction.

g) Compare the position of each indication in the image to the position of the corresponding reflector in the block, either by the plot method (9.4.3.2.2) or the measurement method (9.4.3.2.3).



Key

0 reference point

X_1 probe position from the reference point

X_C distance between the centre of the reference reflector and the reference point

Z_C depth of the centre of the reference reflector from the reference point

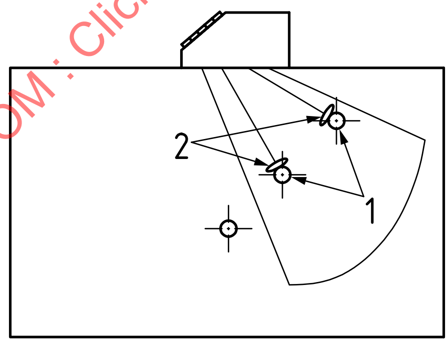
Figure 3 — Distances on a test block

9.4.3.2.2 Verification via the plot method

This plot method may be used if the instrument allows the superimposition of the reference block drawing (e.g. a CAD file), as shown in Figure 4, including the annular bands around each side-drilled hole as defined in Figure 5.

Take into account that the reflection occurs at the surface of the side-drilled hole, not at the centre of the hole.

In this way, it can be verified that the maximum amplitude points on the 2D ultrasonic image are correctly positioned with respect to the position of all the considered reference reflectors.

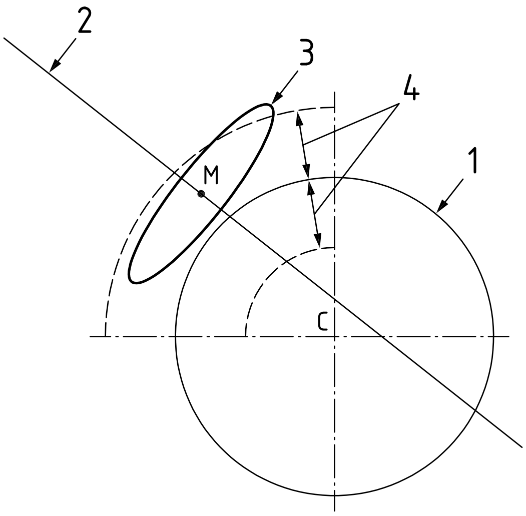


Key

1 reference reflectors

2 maximum amplitude points

Figure 4 — Verification via the plot method



Key

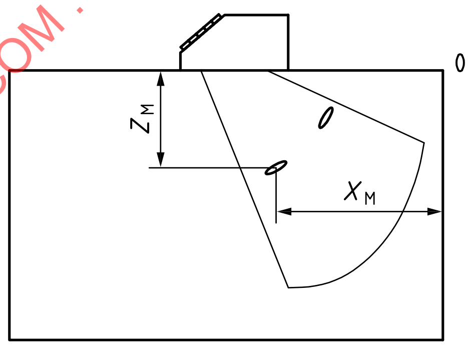
1 side-drilled hole
2 beam axis (only for the phased array technique) through the point of maximum amplitude M of the indication
3 contour of the indication of the reference reflector
4 tolerance from the surface of the reflector
C centre of the reference reflector (X_C; Z_C) (according to Figure 3)
M position of maximum amplitude of the indication (X_M; Z_M) (according to Figure 6)

Figure 5 — Tolerance for position of maximum amplitude

9.4.3.2.3 Verification via measurement

Alternatively to the plot method:

a) Record (e.g. using measurement cursors) the coordinates (X_M; Z_M) of the maximum amplitude points for each of the reflectors displayed, as shown in Figure 6.



Key

X_M distance of the maximum amplitude from the reference point
Z_M depth of the maximum amplitude from the reference point
0 reference point

Figure 6 — Verification via measurement

b) For each reflector, measure or calculate the distance D_{CM} (see Figure 5) between the centre of the side-drilled hole and the maximum amplitude point either by using cursors, if possible with the system, or using Formula (2):

$$D_{\mathrm{CM}} = \sqrt{\left[(X_C - X_M)^2 + (Z_C - Z_M)^2\right]} \quad (2)$$

9.4.3.3 Acceptance criteria

a) For all cases:

1) Each indication shall be located at the probe side of the centre of the hole

2) The position of maximum amplitude shall be located in an annular band as defined in Figure 5,

3) Or the distance D_{CM} shall be approximately equal to the radius r of the side-drilled holes.

b) The tolerance in Figure 5 (half the width of the annular band), or the value $|D_{\mathrm{CM}} - r|$ shall not exceed:

1) For frequency $f \geq 5$ MHz: 0,75 mm;

2) For frequency f with 2 MHz $\leq f <$ 5 MHz: 1 mm;

3) For frequency $f <$ 2 MHz: 1,25 mm.

9.4.3.4 Reporting

The settings and results of the tests shall be recorded on or appended to the system record sheet.

9.4.4 Verification of correct operation by using beams

9.4.4.1 General

As an alternative to the method based on imaging described in 9.4.3, a second method based on measurements is given in this clause.

Only one of these two methods shall be applied.

This second method is only applicable for the phased array technique.

9.4.4.2 Procedure

9.4.4.2.1 General

It is reminded that for the phased array technique, the probe index point position is not an intrinsic feature of the probe as it is for single-transducer probes.

a) For applications using 0°-electronic linear scanning (specific settings of mode 1, mode 2.b, mode 3 or mode 4.b according to Table 3) the probe index points shall be checked for the beams specified in Table 4.

The measurement technique to be applied is described in 9.4.4.2.2.

b) For applications using inclined beams, the angles of refraction and probe index points shall be checked for the beams specified in Table 4.

Two measurement techniques are possible. The most appropriate of the two procedures shall be applied:

1) Determination of probe index point first, and then angle of refraction (9.4.4.2.3).

2) Simultaneous determination of probe index point and angle of refraction (9.4.4.2.4).

c) For matrix array probes generating beams with skew angles, the angles of refraction and probe index points shall be determined in the extreme and median deflection planes by optimising the probe direction on a reference block with side-drilled holes (9.4.5).

9.4.4.2.2 Technique for 0°-electronic linear scanning — Determination of probe index point

To determine the probe index points for straight beams:

a) Use a reference block with at least one side-drilled hole.

The depth of the side-drilled hole shall be in the range of the focal zone depth (for focused beams) or larger than the near field length (for non-focused beams);

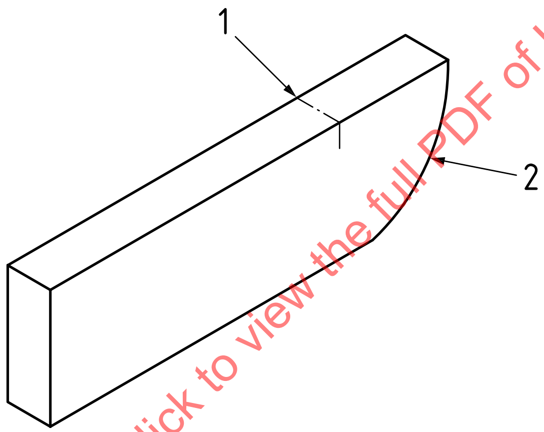
b) Adjust the position of the probe to maximise the echo amplitude from the side-drilled hole.

When the amplitude is at its maximum, the probe index point is vertically aligned with the centre of the side-drilled hole.

c) Repeat step b) for the beams specified in Table 4.

9.4.4.2.3 Technique 1 for inclined beams — Determination of probe index point first, and then angle of refraction

a) To determine the probe index point, use a reference block with a quarter of a cylinder where the cylinder axis is marked on at least one side of the reference block as shown in Figure 7.



Key

1 cylinder axis

2 quarter of cylinder

Figure 7 — Reference block with quarter of cylinder and axis engraved

1) For focused beams, the radius of the cylinder shall be in the range of the focal zone.

2) For non-focused beams, the radius of the cylinder shall be larger than the near field length of the active aperture considered.

An estimation of the near field length N associated with the active aperture may be obtained using Formula (3) or Formula (4):

$$N = D^2/(4\lambda) \quad (3)$$

$$N = (L^2 + W^2)/(4\lambda) \quad (4)$$

where

D is the diagonal of the active aperture in millimetres;

L is the length of the active aperture in millimetres;

W is the width of the active aperture in millimetres;

λ is the wavelength in the material of the reference block in millimetres.

3) Adjust the position of the probe to maximise the echo amplitude from the cylindrical surface. In this position, the probe index point coincides with the engraved centre line of the quarter of the cylinder.

4) Determine and note the position of the probe index point (e.g. by marking the index point on the wedge)

b) To determine the angle of refraction, a reference block featuring a side-drilled hole at a known position shall be used.

This block may bear on one side a scale of the radial angle to the centre of the hole (Figure 8).

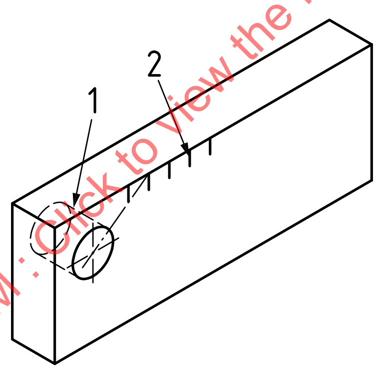
1) For focused beams, the side-drilled hole shall be in the focal zone;

2) For unfocused beams the side-drilled hole shall be at the near field length or beyond;

3) Position the probe on the reference block and look for the echo sent back by the side-drilled hole.

4) Move the probe backward and forward so as to maximize the amplitude of the signal.

5) When the amplitude is at its maximum, determine the angle of refraction either by calculation or by reading on the scale on the block below the measured probe index point.



Key

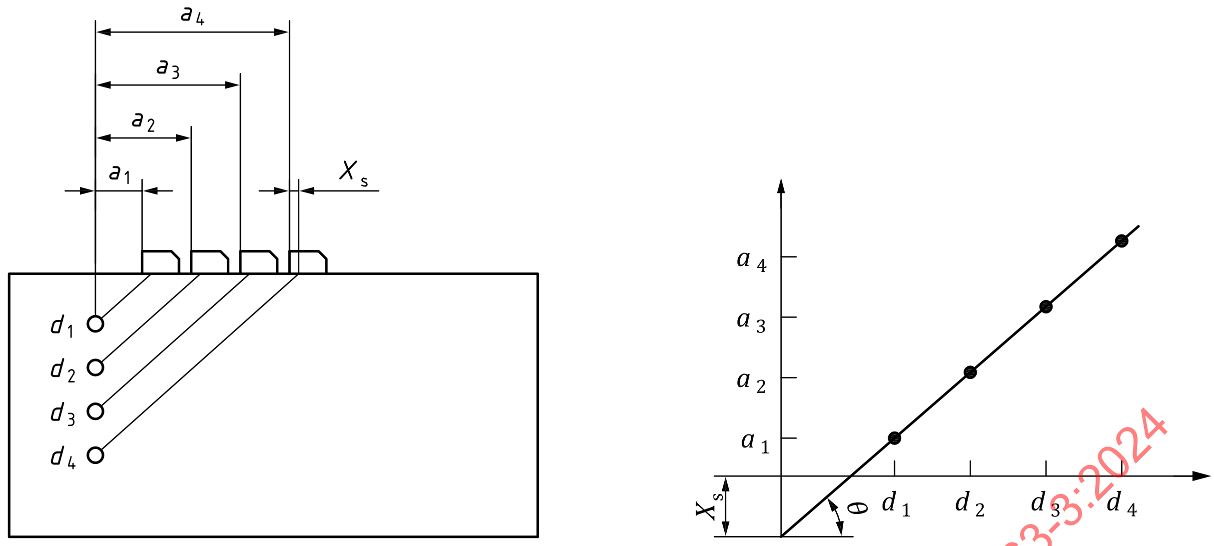
1 side-drilled hole

2 scale of radial angle

Figure 8 — Reference block with a side-drilled hole and an angle scale on one side

9.4.4.2.4 Technique 2 for inclined beams — Simultaneous determination of probe index point and angle of refraction

This method requires the use of a reference block featuring at least four side-drilled holes at different depths (aligned vertically or not), as shown in Figure 9.



a) Test setup **b) Plot of test results**

Key

X_s distance between probe front and probe index point

Θ slope = beam angle

a_i reduced projected sound path length

d_i depth position of the side-drilled hole

Figure 9 — Simultaneous determination of angle of refraction and probe index point

a) Look for the maximum amplitude for the direct echo coming from each hole using A-Scan presentation for a given shot.

b) In each case, measure the reduced projected path length (a_i) between the orthogonal projection of the axis of the hole on the test surface and the front surface of the probe (with a ruler).

c) Plot the depth (d_i) of the holes against these distances (a_i) on a scale drawing of a section through the reference block and draw a straight line through the points.

d) Graphically determine both the probe index point and beam angle simultaneously:

1) The position of the probe index point corresponds to the distance X_s in Figure 9 b)

2) The angle of refraction, Θ, shall be calculated using Formula (5):

$$\Theta = \arctan[(a_i - a_1)/(d_i - d_1)] \qquad (5)$$

9.4.4.3 Acceptance criteria

a) Probe index points shall be within ±1 mm of the base values.

b) For angles of refraction up to 65°, the measured angles of refraction shall be within ±2° of the values specified in the settings of the delay laws.

c) For angles of refraction greater than 65°, the measured angles shall be within ±5° of the specified values.

9.4.4.4 Reporting

The settings and results of the tests shall be recorded on or appended to the system record sheet.

9.4.5 Skew angle

9.4.5.1 General

a) For matrix array probes generating beams with skew angles, the skew angles shall be determined in the extreme and median values.

b) One of three different methods shall be applied to evaluate the skew angles:

   1) with a reference block with side-drilled holes as described in ISO 22232-2;

   2) with a reference block with a corner reflector;

   3) with an electromagnetic-acoustic receiver as described in ISO 22232-2;

9.4.5.2 Procedure

Use one of the methods described in 9.4.5.1 b).

Maximise the signal from the selected reflector by swivelling the probe, and determine the skew angle of the probe.

9.4.5.3 Acceptance criteria

The measured skew angle values shall be equal to the values specified, to ±4°.

9.4.5.4 Reporting

The settings and results of the test shall be recorded on or appended to the system record sheet.

9.5 Other verifications

9.5.1 Squint angle

9.5.1.1 General

It is reminded that the squint angle is typically not intended (e.g. due to an unintended mechanical misalignment of a transducer on a wedge) whereas the skew angle is a setting (e.g. an electronic skew angle or an intended mechanical orientation of the probe on the object to be tested).

a) The squint angle of the probe shall be determined without applying any skew angle.

b) One of three different methods shall be used to evaluate the squint angle of the probe:

   1) with a reference block with side-drilled holes as described in ISO 22232-2;

   2) with a reference block with a corner reflector;

   3) with an electromagnetic-acoustic receiver as described in ISO 22232-2;

9.5.1.2 Procedure

Use one of the methods described in 9.5.1.1 b), maximize the signal from the selected reflector by swivelling the probe, and determine the squint angle of the probe.

9.5.1.3 Acceptance criterion

The measured squint angle shall be equal to the value specified to ±2°.

9.5.1.4 Reporting

The settings and results of the test shall be recorded on or appended to the system record sheet.

9.5.2 Grating lobes (recommended)

9.5.2.1 General

When $p > \lambda/2$ (λ being the wavelength in the first propagation medium and p the pitch of the array), grating lobes may be formed which can hinder detection or characterization by the main beam.

Therefore, this test is recommended whenever $p > \lambda/2$ and when beam steering is required.

One of the following methods shall be used to evaluate the grating lobes of a beam:

a) with a reference block with side-drilled holes;

b) with an electromagnetic-acoustic receiver as described in ISO 22232-2;

c) using simulation software.

9.5.2.2 Procedure

The following sequence shall be used to determine the signals from the selected reflector at different angles of the same beam.

a) Scan the probe over the surface of the reference block, or scan the cylindrical surface of the block with the electromagnetic-acoustic receiver and measure the signal received.

b) Plot the amplitude of the signal against the probe position, or the scanning angle of the electromagnetic-acoustic receiver.

c) Record the local maximum amplitudes and the associated angles.

9.5.2.3 Acceptance criteria

The acceptance criteria depend on the application.

9.5.2.4 Reporting

The settings and results of the test shall be recorded on or appended to the system record sheet.

10 System record sheet

The system record sheet shall include at least the following information:

a) date of the test;

b) International Standard used, including its year of publication;

c) type and serial number of the reference system and the tested identical system (instrument, probe and cables);

d) reference block(s) used;

e) software version used;

f) used channels of the instrument or used part of the array and specific settings for a given mode of operation;

g) tested parameters and the settings (e. g. transmitter voltage, gain, filters);

h) test results of the reference system (base values);

i) results of the tested system and periodical check compared with base values, and compliance with acceptance criteria;

j) name, qualification and dated signature of the test personnel.

Annex A
(informative)

Characterization of sound beams

A.1 General

a) Characterization of sound beams includes the following measurements:

1) probe index point (for contact technique) or point of incidence on the test object (for immersion technique);

2) angle of refraction for angled beams;

3) sensitivity along the beam axis (e.g. distance-amplitude curve);

4) beam dimensions in the area of interest;

5) squint angle for contact technique;

6) grating lobes (measurement and simulation are recommended, if suspected).

b) Depending on the mode of operation, beam characterization shall be carried out on a subset of apertures and/or shots (Table 4).

c) Nevertheless, when the array probe includes dead elements, for Modes 3, 4, 5 and 6, it is necessary additionally to characterize the beams of all the active apertures of the application affected by the presence of those dead elements and compare these beams to the beams of active apertures without dead elements.

d) These additional characterizations may be skipped in any of the following cases:

1) the number of dead elements and their element numbers on each active aperture of the application complies with the acceptance criteria of 9.3.3.6;

2) a software simulation has shown that, for the given application, the dead elements have no influence on the beams compared to the beams generated with all elements working properly;

3) an experimental simulation of dead elements has been performed by switching off one or multiple elements and has shown that, for the given application, the dead elements have no influence on the beams compared to the beams generated with all elements working properly.

A.2 Beam characterization for the contact technique

A.2.1 General

Tests may be performed with devices for automated movements of the probe.

a) Tests shall be performed with the parameters identified for the application.

b) Before each determination of a parameter, check the amplification system (9.4.2).

c) Depending on the settings available on the instrument used, beam characterization may be performed by applying one set of parameters which produces all the beams or by successively applying the settings that will produce each beam.

For example, in the case of electronic sectorial scanning, it is possible to characterize the beams corresponding to the extreme and median delay laws:

1) by application of a single set of parameters corresponding to the electronic sectorial scanning and carrying out measurements on each of the three beams of the sectorial scanning, or

2) by application of three sets of parameters and carrying out measurements on each of the three beams.

d) In the case of wedges or delay lines with a flat contact surface, flat reference blocks shall be used.

e) In the case of wedges or delay lines with a contoured contact surface, reference blocks with the same contour shall be used.

A.2.2 Angle of refraction and probe index point

See 9.4.4.2.

A.2.3 Sensitivity along the beam axis

A.2.3.1 General

a) For contact technique, the test shall be performed manually or with an automated scanning device, using equal reflectors at different distances, by recording the amplitudes of the echoes and the corresponding sound path.

If the instrument supports an automated recording of the sensitivity along the beam axis, like a distance-amplitude curve or an automated correction feature like time-corrected gain (TCG), this instrument feature may be used for the characterization of the beam.

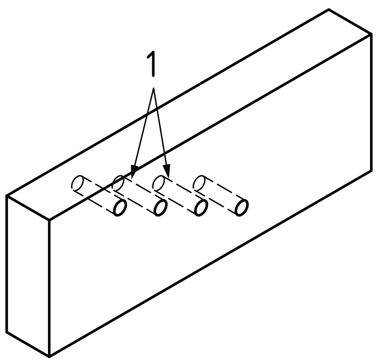
b) The TCG depends on the application and shall be verified following the test operating procedure.

c) Alternatively, the sensitivity along the beam axis may be determined and documented manually.

d) The tests require the use of a reference block with reflectors in the area of interest.

Side-drilled holes are recommended as shown in Figure A.1.

NOTE Planar reflectors (like flat-bottomed holes) can be used but are less practical because they are only suitable for beam angles that impinge perpendicular on the reflector.



Key

1 side-drilled holes

Figure A.1 — Example of a reference block with equal diameter side-drilled holes