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

Part 2: Array probes

Essais non destructifs — Caractérisation et vérification de l'appareillage de contrôle par ultrasons en multiéléments —

Partie 2: Traducteurs multiéléments

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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 documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by ISO Technical Committee 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 18563-2:2017), which has been technically revised.

The main changes are as follows:

— terminology and types of array probes modified according to ISO 23243;

— the wording ‘measurement’ is replaced by ‘determination’ or ‘evaluation’, where applicable.

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 2: Array probes

1 Scope

This document specifies characterization tests to be performed at the end of the fabrication of an array probe. It defines both methodology and acceptance criteria.

This document is applicable to the following array probes used for ultrasonic non-destructive testing [phased array technique or signal processing technique, e.g. full-matrix capture (FMC) and total-focusing technique (TFM)] in contact technique (with or without a wedge or delay line) or in immersion technique, with centre frequencies in the range 0,5 MHz to 10 MHz:

a) array probes with elements in one direction:
   - 1-D-linear array (linear array);
   - 1-D-curved array;
   - annular array;

b) array probes with elements in two directions:
   - 2-D-array (matrix array);
   - sectorial annular array;
   - partial sectorial annular array.

This document does not give methods and acceptance criteria to characterize the performance of an ultrasonic phased array instrument or the performance of a complete system, which are given in ISO 18563–1 and in ISO 18563–3.

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 2400, *Non-destructive testing — Ultrasonic testing — Specification for calibration block No. 1*

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

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
array probe data sheet
document giving technical specifications of the same type of array probes

3.2
array probe test report
document giving the determined values of the required parameters of one specific array probe, including test equipment and test conditions

4 Quantities and symbols

A full list of the quantities, units and symbols used throughout this document is given in Table 1.

Table 1 — Quantities, units and symbols

Symbol	Unit	Meaning
A_{CT}	dB	Inter-element cross-talk attenuation
f_0	Hz	Centre frequency
f_u	Hz	Upper cut-off frequency at –6 dB
f_l	Hz	Lower cut-off frequency at –6 dB
Δf	Hz	Frequency bandwidth
Δf_{rel}	%	Relative bandwidth
S_{el}	dB	Relative pulse-echo sensitivity variation of each element
S_{pr}	dB	Array probe sensitivity
V_{av}	V	Arithmetic mean of V_{el}
V_{el}	V	Amplitude of reflector echo of each element
V_{exc}	V	Amplitude of excitation burst
V_{rec}	V	Amplitude received by an adjacent element
V_{ref}	V	Amplitude of reference exciting signal

5 General compliance

The array probe shall be in accordance with the following requirements:

a) An array probe data sheet shall be available corresponding to the array probe which specifies the performance criteria in accordance with Clause 6.

b) The array probe shall comply with Clause 8.

c) The array probe shall be clearly marked to identify the manufacturer and shall either carry a unique serial number or shall show a permanent reference number from which information can be traced to the array probe data sheet.

d) An array probe test report shall be delivered together with the array probe, giving the determined values of the required parameters of one specific array probe, including at least the technical information given in Clause 6, the used test equipment and its settings according to Clause 7 and all test results according to Clause 8.

e) A statement of conformity shall be available, issued by either the manufacturer, by the purchaser or by a third party that could be a test laboratory.

6 Technical information for array probes

Technical information listed in Table 2 shall be supplied with the array probe. Optional technical information is listed in Table 3; details of the measurement or determination shall be given by the manufacturer.

Table 2 — Required information to be given in an array probe data sheet or array probe test report

Required information	Information type	Comments
Trade name	OI	—
Identification	OI	Serial number, reference
Array probe type	OI	—
Array probe dimensions	OI	Outer dimensions
Geometry of the array	OI	Shape, orientation, arrangement, dimension, pitch, space between elements and element dimensions
Type of connector	OI	Commercial name
Wiring plan	OI	Details of connections between elements and connector
Cable	OI	Cable length, outer diameter and outer material
Dimensions, geometry and material of integrated wedge or delay line	OI	Only valid for contact probes with integrated wedge or delay line
Physical aspects	OI	E.g. housing material and shape of the contact face; see 8.2
Nominal frequency, nominal relative bandwidth, nominal pulse duration	OI	—
Frequency, bandwidth and pulse duration	M	Determined for each element; see 8.4
Average centre frequency, average bandwidth and average pulse duration	M	Calculated for the array probe; see 8.4
Relative pulse-echo sensitivity	M	See 8.3
Nominal array probe sensitivity	OI	—
Array probe sensitivity	M	See 8.5
Nominal inter-element cross-talk attenuation	OI	Minimum value of the inter-element cross-talk attenuation
Maximum allowable squint angle (for contact probes only)	OI	Maximum value of the squint angle with indication of the plane of reference
Echo from the transducer backing	OI	Maximum amplitude of the backing echo compared to a reference echo (dB difference)
Environmental conditions	OI	E.g. temperature range, humidity, sealing, pressure
Equipment and procedure reference used for characterization tests	OI	—
Special conditions	OI	E.g. for storage, for protection during transportation

Key

M = measurement or determination

OI = other information

Table 3 — Optional technical information to be given

Optional information	Information type	Comments
General drawing and tolerances	OI	—
Inter-element cross-talk attenuation	M	Determined cross-talk attenuation corresponding to the array probe; see 8.6
Squint angle (for contact probes only)	M	Measured squint angle with indication of the plane of reference
Echo from the transducer backing	M	Amplitude of the backing echo compared to a reference echo (dB difference)
Key M = measurement or determination OI = other information		

7 Test equipment

7.1 Electronic equipment

a) The equipment used for the tests specified in Clause 8 shall be stated in the array probe test report.

b) The equipment shall be checked periodically.

c) The ultrasonic instrument (or laboratory pulser-receiver) shall comply with ISO 22232-1 or with ISO 18563-1, if applicable.

d) Testing shall be carried out with the probe cables and matching devices specified on the array probe data sheet.

e) In addition to the ultrasonic instrument or laboratory pulser-receiver, the following electronic equipment or its equivalent is essential to test array probes in accordance with this document:

   1) an oscilloscope with a minimum analogue bandwidth of 100 MHz;

   2) a frequency spectrum analyser with a minimum bandwidth of 100 MHz or an oscilloscope performing Fast Fourier Transform (FFT).

7.2 Test setup

7.2.1 General

a) Array probes can be used in contact technique (with or without a wedge or delay line) or in immersion technique. Depending on this, the performance tests shall be carried out under corresponding conditions.

b) Details of the test block (geometry, material, reflector type, shape and position, sound velocity) shall be stated in the array probe test report.

c) For partial sectorial annular array probes, the tests shall be performed directly on a flat reflector.

7.2.2 Contact technique

a) If the wedge or delay line can be removed, the tests shall preferably be performed without the wedge or delay line.

b) Without wedge or delay line: a block of the material to be tested shall be used so that the total sound path is the same for each element.

c) If no material is specified, a block of steel grade according to ISO 2400 shall be used.

d) With wedge (integrated or not integrated): a block of the same material as the wedge and proper dimensions shall be used so that the total sound path is the same for each element.

7.2.3 Immersion technique

a) Tests shall be carried out in immersion fluid using a defined reflector.

b) If no fluid is specified, water shall be used.

8 Performance tests for array probes

8.1 General

Performance tests shall be performed at the probe connector once the array probe is completely assembled.

It should be noted that acceptance criteria are only valid under the test conditions defined for the considered array probe.

For array probes with elements in two directions, a limited number of elements which do not fulfil the criteria is acceptable. The criteria are specified in 8.7.

8.2 Physical aspects

8.2.1 Method

a) Visually inspect the outside of the array probe for correct identification and assembly.

b) Verify that the physical geometry of the array probe complies with the intended design.

8.2.2 Acceptance criterion

The physical aspects of the array probe shall fall within the prescribed tolerances stated in the array probe data sheet.

8.3 Relative pulse-echo sensitivity variation

8.3.1 General

The determination of the relative pulse-echo sensitivity shall be carried out on all elements of the same shape and size.

8.3.2 Method

a) The determination shall be performed in transmit–receive mode using a setup according to 7.2.

b) The transmitter pulse shall be a negative spike pulse or a negative square pulse. In case of a negative square pulse a pulse duration of half the period corresponding to the nominal probe frequency is recommended.

c) The echo of the reflector shall be placed in a time window, the duration of which is at least twice the echo pulse duration measured at –20 dB of the echo amplitude.

d) The amplitude in volts, V_{el}, of the reflector echo of each element shall be measured and recorded.

e) The arithmetic mean value, V_{av}, of the V_{el} amplitudes shall be calculated and recorded.

f) The relative pulse-echo sensitivity variation, S_{el}, of each element shall be calculated using Formula (1):

$$S_{el} = 20 \lg \frac{V_{el}}{V_{av}} \quad (1)$$

8.3.3 Acceptance criteria

8.3.3.1 Array probes with elements in one direction

a) The relative pulse-echo sensitivity variation, S_{el}, over all the elements shall be within ±3 dB for all elements having the same size and shape.

b) For 1-D-curved arrays, the variation over all the elements shall be within ±4 dB.

8.3.3.2 Array probes with elements in two directions

a) For partial sectorial annular arrays, the variation over all the elements shall be within ±4 dB.

b) For all other array probes with elements in two directions, the relative pulse-echo sensitivity variation, S_{el}, over all the elements shall be as given in Table 4.

Table 4 — Acceptable relative sensitivity variation for array probes with elements in two directions

Frequency (MHz)	Element area ≥ 1 mm²		
	$n \leqq 64$	$64 < n \leqq 128$	$128 < n \leqq 512$
$0{,}5 \leqq f \leqq 1$	±5 dB	±5 dB	±5 dB
$1 < f \leqq 1{,}5$	±4 dB	±4 dB	±5 dB
$1{,}5 < f \leqq 5$	±3 dB	±4 dB	±5 dB
$5 < f \leqq 10$	±4 dB	±5 dB	±5 dB
	Element area < 1 mm²		
$0{,}5 \leqq f \leqq 10$	±5 dB	±5 dB	±5 dB
n: total number of elements.			

8.4 Frequency, bandwidth and pulse duration

8.4.1 General

Evaluations shall be done for each element of the array probe, excluding elements that are out of specification according to 8.3.3.

8.4.2 Method

a) The evaluation shall be performed in transmit–receive mode using a setup according to 7.2.

b) The evaluation shall be performed under the same conditions as those for 8.3.

c) The frequency spectrum shall be determined on the signal in the used time window.

d) The frequencies intersecting the spectrum at –6 dB of the maximum amplitude of the spectrum shall be determined.

e) From the upper and lower cut-off frequencies, f_u and f_l, obtained, the centre frequency, f_0, shall be calculated using Formula (2):

$$f_0 = \frac{f_u + f_l}{2} \quad (2)$$

f) The bandwidth shall be calculated using Formula (3):

$$\Delta f = f_u - f_l \quad (3)$$

g) The relative bandwidth shall be calculated in % using Formula (4):

$$\Delta f_{rel} = \left(\frac{\Delta f}{f_0} \right) \times 100 \quad (4)$$

h) The average centre frequency as the average of the calculated f_0 values shall be recorded.

i) The average relative bandwidth as the average of the calculated Δf_{rel} values shall be recorded.

j) The echo pulse duration shall be measured at –20 dB of the echo amplitude.

k) The average echo pulse duration shall be calculated and recorded.

8.4.3 Acceptance criteria

a) The average centre frequency shall be within ±10 % of the nominal frequency stated in the array probe data sheet.

b) The centre frequency of each element shall be within ±10 % of the average centre frequency.

c) The average relative bandwidth shall be equal to or larger than the relative bandwidth stated in the array probe data sheet.

d) The average pulse duration shall be smaller than or equal to the pulse duration stated in the array probe data sheet.

8.5 Array probe sensitivity

8.5.1 General

a) Evaluations shall be done to compare array probes of the same design.

b) For array probes manufactured in smaller quantities (<10), no acceptance criteria for array probe sensitivity are specified in this document.

8.5.2 Method

a) The evaluations shall be performed under conditions as those for 8.3.

b) The reference excitation signal amplitude, V_{ref}, shall be determined with one channel of the instrument considering one element connected.

c) The signal shall be considered as the reference excitation signal used for all elements.

d) The average element sensitivity (arithmetic mean), V_{av}, over all elements shall be calculated (see 8.3.2).

e) The array probe sensitivity, S_{pr}, shall be calculated using Formula (5):

$$S_{pr} = 20 \lg \frac{V_{av}}{V_{ref}} \quad (5)$$

8.5.3 Acceptance criteria

8.5.3.1 General

The following acceptance criteria are valid only for array probes based on the same design manufactured in quantities ≥ 10.

8.5.3.2 Array probes with elements in one direction

The array probe sensitivity, S_{pr}, shall be within ±3 dB of the value stated in the array probe data sheet.

8.5.3.3 Array probes with elements in two directions

The array probe sensitivity, S_{pr}, shall be within ±5 dB of the value stated in the array probe data sheet.

8.6 Inter-element cross-talk attenuation (optional)

8.6.1 General

The inter-element cross-talk attenuation shall be determined on two locations for an array with up to 64 elements and on four locations for an array with more than 64 elements.

8.6.2 Method

a) The inter-element cross-talk attenuation shall be determined by exciting one element selected randomly and evaluating the signals received on the adjacent elements.

   A network analyser can be used for a direct evaluation.

b) When the evaluations are performed using an oscilloscope, the excitation signal should be a sine burst of the nominal frequency with a duration of at least six periods.

c) The cross-talk attenuation shall be determined by connecting an oscilloscope or network analyser to an adjacent element.

   1) In case of a contact probe, the array probe's matching face shall be in contact with a test block.

   2) In case of an immersion probe, the array probe shall be immersed.

d) The setup shall be chosen in a way that the evaluation is not influenced by reflections from the test block or from the immersion tank.

e) Inter-element cross-talk attenuation, A_{CT}, shall be calculated as follows:

$$A_{CT} = 20 \lg \frac{V_{exc}}{V_{rec}} \tag{6}$$

where

V_{rec} is the voltage received by an adjacent element;

V_{exc} is the voltage of the excitation burst.

8.6.3 Acceptance criterion

The inter-element cross-talk attenuation according to Formula (6) shall be at least 25 dB.

8.7 Number of elements out of specification

8.7.1 General

This subclause defines the maximum allowable number of elements out of specification.