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Non-destructive testing — Characterization and verification of ultrasonic test equipment —

Part 2: Probes

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

Partie 2: Traducteurs

Reference number
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Contents

Page

Foreword

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

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

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

This document was prepared by Technical Committee ISO/TC 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).

A list of all parts in the ISO 22232 series can be found on the ISO website.

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Non-destructive testing — Characterization and verification of ultrasonic test equipment —

Part 2:
Probes

1 Scope

This document specifies the characteristics of probes used for non-destructive ultrasonic testing in the following categories with centre frequencies in the range of 0,5 MHz to 15 MHz, focusing or without focusing means:

a) single- or dual-transducer contact probes generating longitudinal and/or transverse waves;

b) single-transducer immersion probes.

Where material-dependent ultrasonic values are specified in this document they are based on steels having a sound velocity of (5 920 ± 50) m/s for longitudinal waves, and (3 255 ± 30) m/s for transverse waves.

This document excludes periodic tests for probes. Routine tests for the verification of probes using on-site procedures are given in ISO 22232-3.

If parameters in addition to those specified in ISO 22232-3 are to be verified during the probe's life time, as agreed upon by the contracting parties, the procedures of verification for these additional parameters can be selected from those given in this document.

This document also excludes ultrasonic phased array probes, therefore see ISO 18563-2.

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 7963, *Non-destructive testing — Ultrasonic testing — Specification for calibration block No. 2*

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

ISO/IEC 17050-1, *Conformity assessment — Supplier's declaration of conformity — Part 1: General requirements*

3 Terms and definitions

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

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

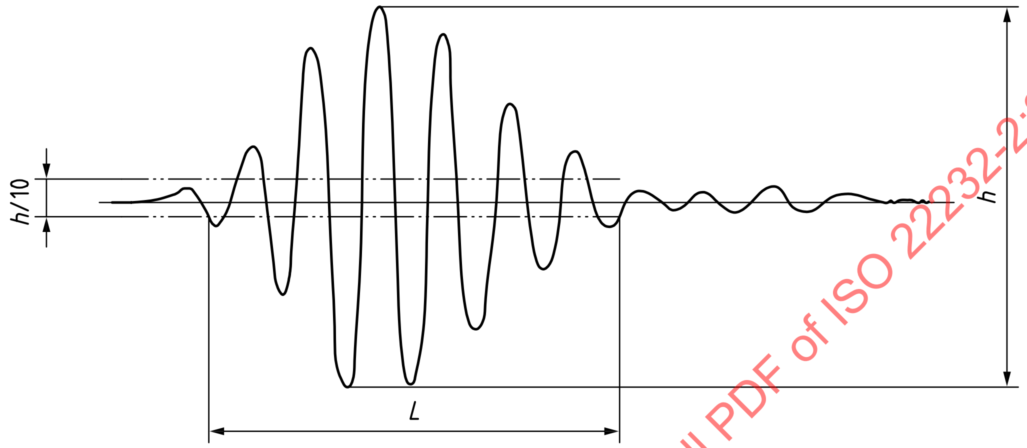
— ISO Online browsing platform: available at https://www.iso.org/obp

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

3.1
horizontal plane
<angle-beam probes> plane perpendicular to the *vertical plane* (3.7) of the sound beam including the beam axis in the material

3.2
peak-to-peak amplitude
difference between the highest positive and the lowest negative amplitude in a pulse

Note 1 to entry: See Figure 1.



Key

h peak-to-peak amplitude

L pulse duration

Figure 1 — Typical ultrasonic pulse

3.3
probe data sheet
document giving manufacturer's technical specifications of the same type of probes, i.e. probes manufactured in series

Note 1 to entry: The data sheet does not necessarily need to be a test certificate of performance.

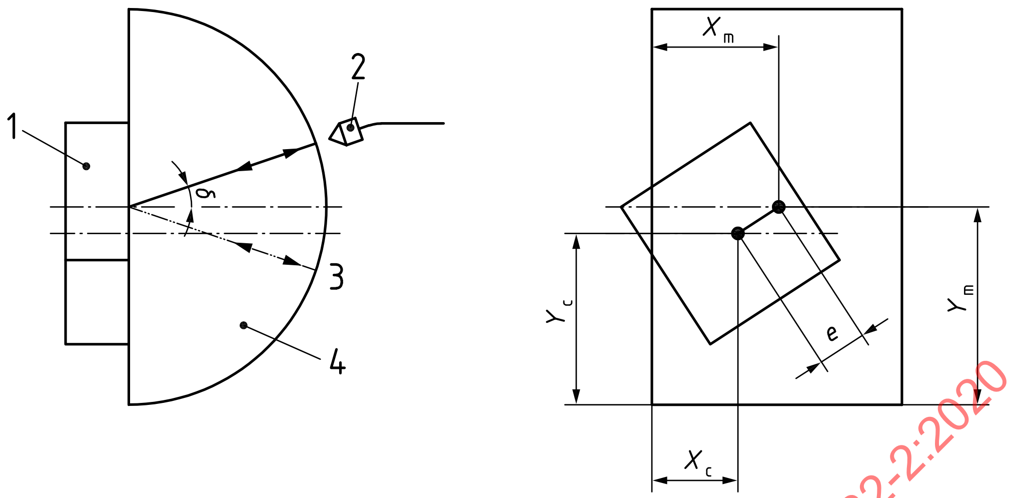
Note 2 to entry: For individually designed or manufactured probes, some parameters may not be accurately known before manufacturing.

3.4
probe test report
document showing compliance with this document giving the measured values of the required parameters of one specific probe, including test equipment and conditions

3.5
reference side
right side of an angle-beam probe looking in the direction of the beam, unless otherwise specified by the manufacturer

3.6
squint angle for straight-beam probes
deviation between the beam axis and the line perpendicular to the coupling surface at the point of incidence

Note 1 to entry: See Figure 2.



Key

1 ultrasonic straight-beam probe
2 EMA receiver
3 echo point
4 hemicylindrical test block

e offset
δ squint angle for straight-beam probes
X_c, Y_c coordinates of the centre of the probe
X_m coordinate of EMA receiver
Y_m coordinate of the centre of the block

Figure 2 — Squint angle and offset for a straight-beam probe

3.7
vertical plane
<angle-beam probes> plane through the beam axis of a sound beam in the probe wedge and the beam axis in the test object

3.8
wear allowance
maximum wear of the probe contact surface which does not affect the performance of the probe

Note 1 to entry: Wear allowance is typically expressed in millimetres.

4 Symbols

Symbol	Unit	Meaning
L	us	Pulse duration
h	V	Peak-to-peak amplitude
f_o	Hz	Centre frequency
f_u	Hz	Upper cut-off frequency
f_l	Hz	Lower cut-off frequency
Δf	Hz	Bandwidth
Δf_{rel}	%	Relative bandwidth
S	dB	Pulse-echo sensitivity
N_0	mm	Near field length
F_D	mm	Focal distance
F_L	mm	Length of focal zone at −6 dB using a reflector or −3 dB using a hydrophone
Z_P	mm	Focal point
W_x	mm	Focal width on X-axis

Symbol	Unit	Meaning
W_y	mm	Focal width on Y-axis
Ω_X	°	Angle of beam divergence in X direction
Ω_Y	°	Angle of beam divergence in Y direction
X	mm	Probe index point
α	°	Beam angle
δ	°	Squint angle for straight-beam probes

5 General requirements of conformity

An ultrasonic probe complies with this document if it fulfils all of the following requirements:

a) the probe shall comply with Clause 8;

b) a declaration of conformity according to ISO/IEC 17050-1 shall be available;

c) the ultrasonic probe shall be clearly marked to identify the manufacturer, and carry a unique serial number or show a permanent reference number from which information can be traced to the data sheet and probe test report;

d) a probe data sheet corresponding to the ultrasonic probe shall be available, which defines the performance criteria for the items given in Clause 6;

e) a probe test report shall be delivered together with the probe, which includes at least the test results given in Clause 6.

Table 1 summarises the tests to be performed on ultrasonic probes.

Table 1 — List of tests for ultrasonic probes

Title of test	Manufacturer's tests
	Subclause
Physical aspects	8.1
Pulse shape, amplitude and duration	8.2
Frequency spectrum and bandwidth	8.3
Pulse-echo sensitivity	8.4
Distance-amplitude curve	8.5
Beam parameters for immersion probes	8.6
Axial profile – Focal distance and length of the focal zone	8.6.2.2
Transverse profile – Focal width	8.6.2.3
Transverse profile – Beam divergence	8.6.2.4
Beam profile by scanning means – Focal distance and focal length	8.6.3.2
Beam profile by scanning means – Focal width and beam divergence	8.6.3.3

Table 1 *(continued)*

Title of test	Manufacturer's tests
	Subclause
Beam parameters for straight-beam single-transducer contact probes	8.7
Beam divergence and side lobes	8.7.2
Squint angle and offset for straight-beam probes	8.7.3
Focal distance (near field length)	8.7.4
Focal width	8.7.5
Length of the focal zone	8.7.6
Beam parameters for angle-beam single-transducer contact probes	8.8
Index point	8.8.2
Beam angle and beam divergence	8.8.3
Squint angle and offset	8.8.4
Focal distance (near field length)	8.8.5
Focal width	8.8.6
Length of the focal zone	8.8.7
Beam parameters for straight-beam dual-transducer contact probes	8.9
Delay line delay path	8.9.2
Focal distance	8.9.3
Axial sensitivity range (focal width)	8.9.4
Lateral sensitivity range (focal width)	8.9.5
Beam parameters for angle-beam dual-transducer contact probes	8.10
Index point	8.10.2
Beam angle and profiles	8.10.3
Wedge delay path	8.10.4
Distance to sensitivity maximum (focal distance)	8.10.5
Axial sensitivity range (length of the focal zone)	8.10.6
Lateral sensitivity range (focal width)	8.10.7
Crosstalk	8.11

6 Technical information for probes

6.1 General

The test conditions and the equipment used for the evaluation of the probe parameters shall be listed (see Table 2).

For individually designed or manufactured probes some parameters may not be accurately known prior to manufacturing. In that case the measured values shall be used as reference values.

6.2 Probe data sheet

The probe data sheet gives the list of information to be reported for all probes within the scope of this document (see Table 2).

6.3 Probe test report

The probe test report gives the measured values of the required parameters of one specific probe and other information from the probe data sheet (see Table 2).

The probe test report shall include the unique serial number or the permanent reference number to provide a uniquely assignment between the specific probe and the probe test report.

Table 2 — List of information to be given in a probe data sheet and a probe test report

Information to be given	Probe data sheet	Probe test report	Comment
Manufacturer's name	I	I	—
Probe type	I	I	—
Probe serial number	—	I	—
Probe housing dimensions	I	I	—
Probe weight	I	I	—
Type of connectors	I	I	—
Connectors interchangeability	I	I	Only for dual-transducer probes
Crosstalk	I	M	Only for dual-transducer probes
Transducer material	I	I	—
Shape and size of transducer	I	I	—
Roof angle of transducers	I	I	Only for dual-transducer probes
Wedge material	I	I	Only for angle-beam probes
Wedge delay path	I	I	Only for angle-beam probes,
Delay line material	I	I	Only for straight-beam probes
Delay line delay	I	I	Only for straight-beam probes,
Protection layer material	I	I	—
Wear allowance	I	I	—
Pulse shape	I	M	—
Frequency spectrum	I	M	—
Centre frequency	I	M	—
Bandwidth	I	M	—
Pulse duration	I	M	—
Pulse-echo sensitivity	I	M	—
Beam angle	I	M	Only for angle-beam probes
Angles of divergence	I	I	Not for focusing immersion probes
Squint angle	I	I	—
Squint offset	I	I	—
Probe index point	I	I	Only for angle-beam probes Alternatively the distance between the probe index point and the front of the probe can be given
Type of focus	I	I	—
Focal distance or near field length	I	I	—
Width of the focal zone	I	I	Only for focusing probes
Length of the focal zone	I	I	Only for focusing probes
Operating temperature range	I	I	—
Storage temperature range	I	I	—
DAC	I	—	—
Distance-amplitude curve available	I	—	—

Key

I information

M measurement

Table 2 *(continued)*

Information to be given	Probe data sheet	Probe test report	Comment
Used equipment	I	I	—
Test conditions	I	I	—
Physical aspects	—	I	—
Key I information M measurement			

7 Test equipment

7.1 Electronic equipment

The ultrasonic instrument (or laboratory pulser/receiver) used for the tests specified in Clause 8 shall be of the type designated on the probe data sheet and shall comply with ISO 22232-1 as applicable.

Where more than one type of ultrasonic instrument is designated the tests shall be repeated with each of the additional designated types.

Testing shall be carried out with the probe cables and electrical matching devices specified on the probe data sheet for use with the particular type of ultrasonic instrument.

NOTE Probe leads more than about 2 m long can have a significant effect on probe performance.

In addition to the ultrasonic instrument or laboratory pulser/receiver the items of equipment essential to assess probes in accordance with this document are as follows:

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

b) a frequency spectrum analyser with a minimum bandwidth of 100 MHz, or an oscilloscope/digitiser or computer capable of performing discrete Fourier transforms (DFT).

The following additional equipment is optional:

c) for contact probes only:

   1) an electromagnetic-acoustic probe (EMA) and receiver;

   2) a plotter to plot directivity diagrams;

d) for immersion probes only:

   a hydrophone receiver with an active diameter less than two times the central ultrasonic wavelength of the probe (centre frequency) under test but not less than 0,5 mm. The bandwidth of the hydrophone and the amplifier shall cover the bandwidth of the probe under test.

7.2 Test blocks and other equipment

For contact probes to be used on carbon steel, the test block quality shall be as defined in ISO 7963. For contact probes to be used on other materials such as stainless steel, aluminum, titanium or plastics, the test block material shall be documented in the probe data sheet or probe test report including the measured sound velocity. The sound attenuation of other materials, especially plastics, shall be considered.

The following test blocks and additional equipment shall be used to carry out the specified range of tests, for contact probes:

a) Hemicylindrical blocks with different radii (R) in the range from 12 mm to 200 mm. Steps of $R\sqrt{2}$ are recommended. The length of each block shall be equal to or larger than its radius, up to a maximum length of 100 mm. An example is shown in Figure 3.

b) Blocks with parallel faces and different thicknesses in the range from 12 mm to 200 mm. The length and width of each block shall be equal to or larger than its thickness, up to a maximum thickness of 100 mm.

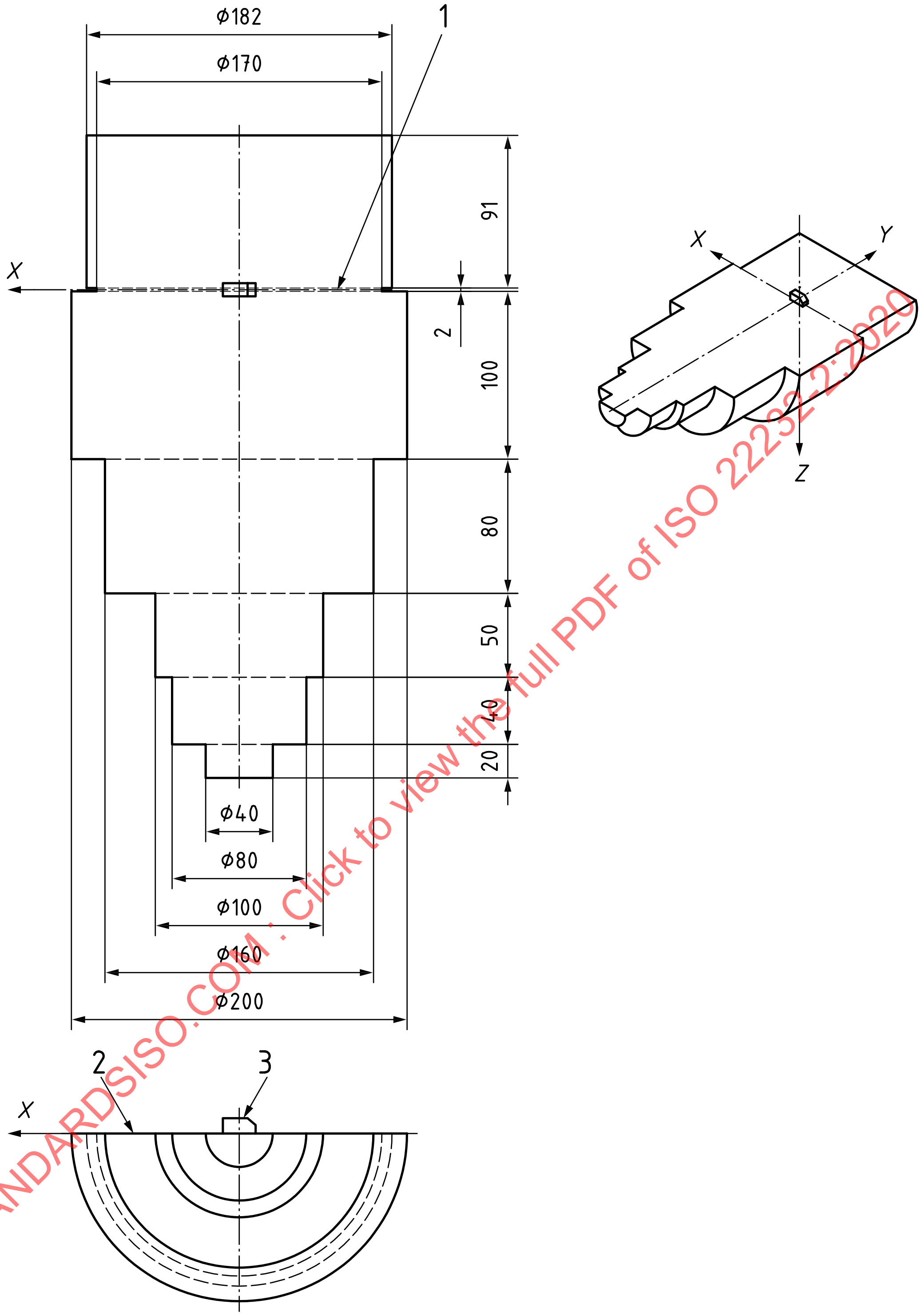
c) Blocks with side-drilled holes parallel to the test surface, of preferably 3 mm or 1,5 mm diameter as shown in Figure 4 or Figure 5, respectively. For probes with centre frequencies up to 2 MHz side-drilled holes of 5 mm diameter are recommended. The blocks shall meet the following requirements:

    1) the length, height and width shall be such that the sides of the blocks do not interfere with the ultrasonic beam;

    2) the depth positions of the holes shall be such that at least three holes fall outside the near field;

    3) the position of the holes shall be such that the signals do not interfere, e. g. the amplitude shows a drop of at least 26 dB between two adjacent holes.

Dimensions in millimetres



Key

1 centre line of slot

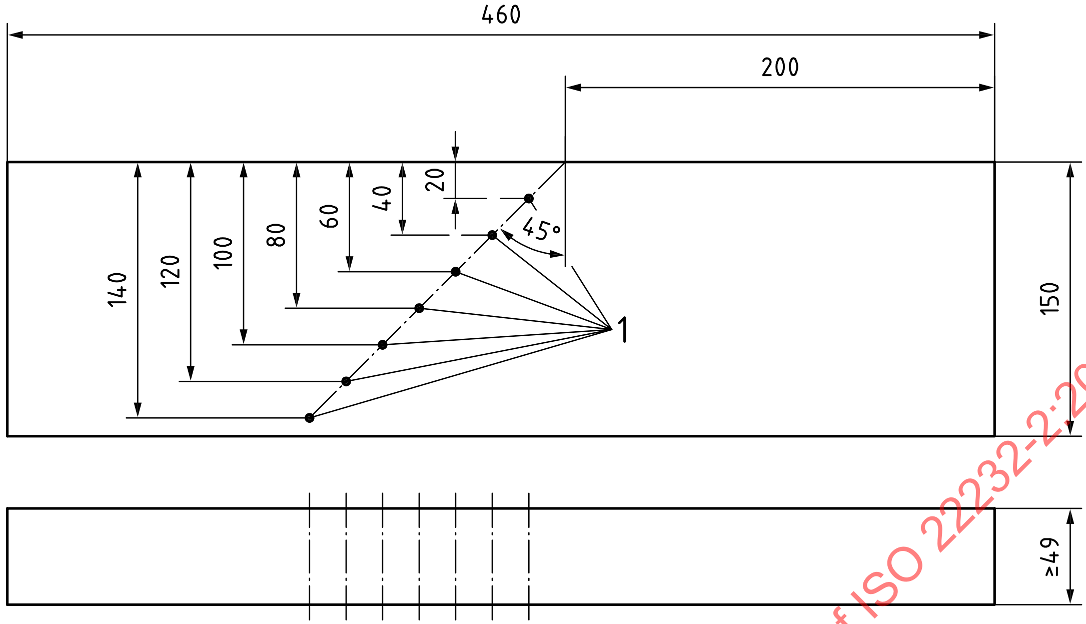
2 front surface

3 angle-beam probe

X, *Y*, *Z* coordinate system of hemicylindrical-stepped block

Figure 3 — Example of a hemicylindrical-stepped block

Dimensions in millimetres

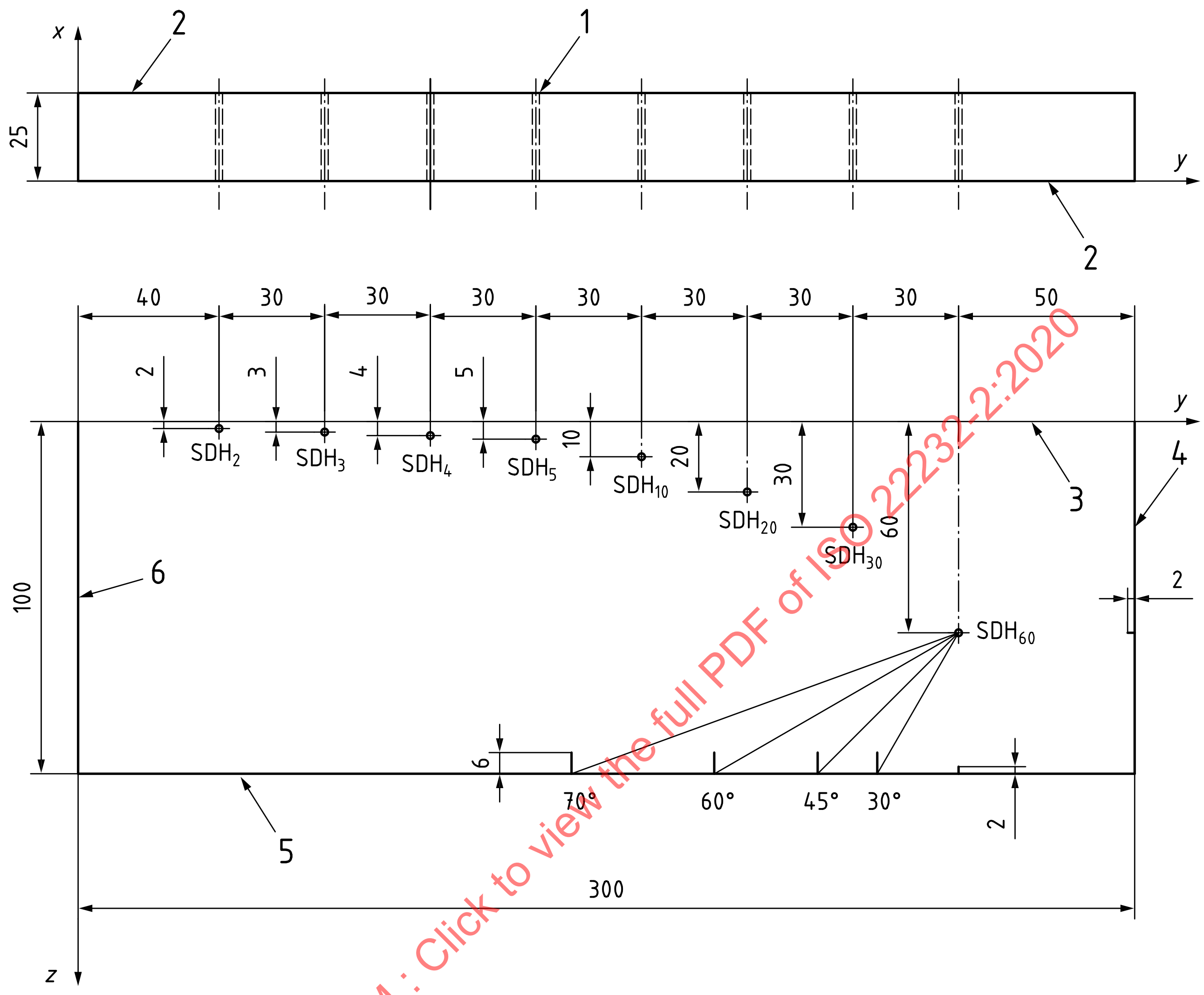


Key

1 side-drilled hole (SDH) of diameter 3 mm

Figure 4 — Example of a test block with 3 mm side-drilled holes

Dimensions in millimetres



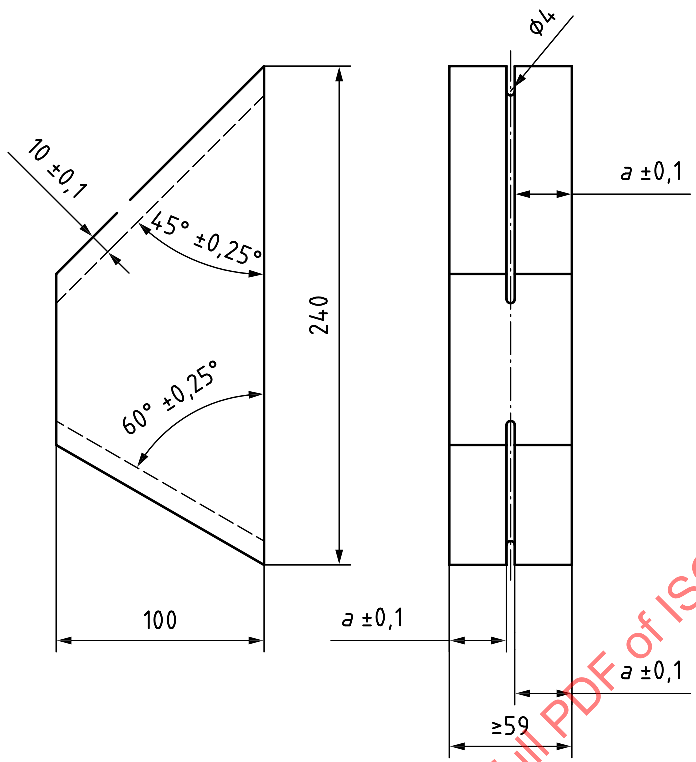
Key

1	side-drilled hole (SDH) of diameter 1,5 mm	SDH_n	side-drilled hole at depth position n
2	front surface	*x*	width coordinate
3	top surface	*y*	length coordinate
4	right surface	*z*	depth coordinate
5	bottom surface		
6	left surface		

Figure 5 — Example of a test block with side-drilled holes (SDH)

d) Blocks with inclined faces with a notch as shown in Figure 6 and blocks with hemispherical-bottomed holes as in Figure 7. These blocks are used to measure the beam divergence in the vertical and horizontal plane respectively.

Dimensions in millimetres



Key

a tolerance of centre line position

Figure 6 — Example of a test block with notches

Dimensions in millimetres

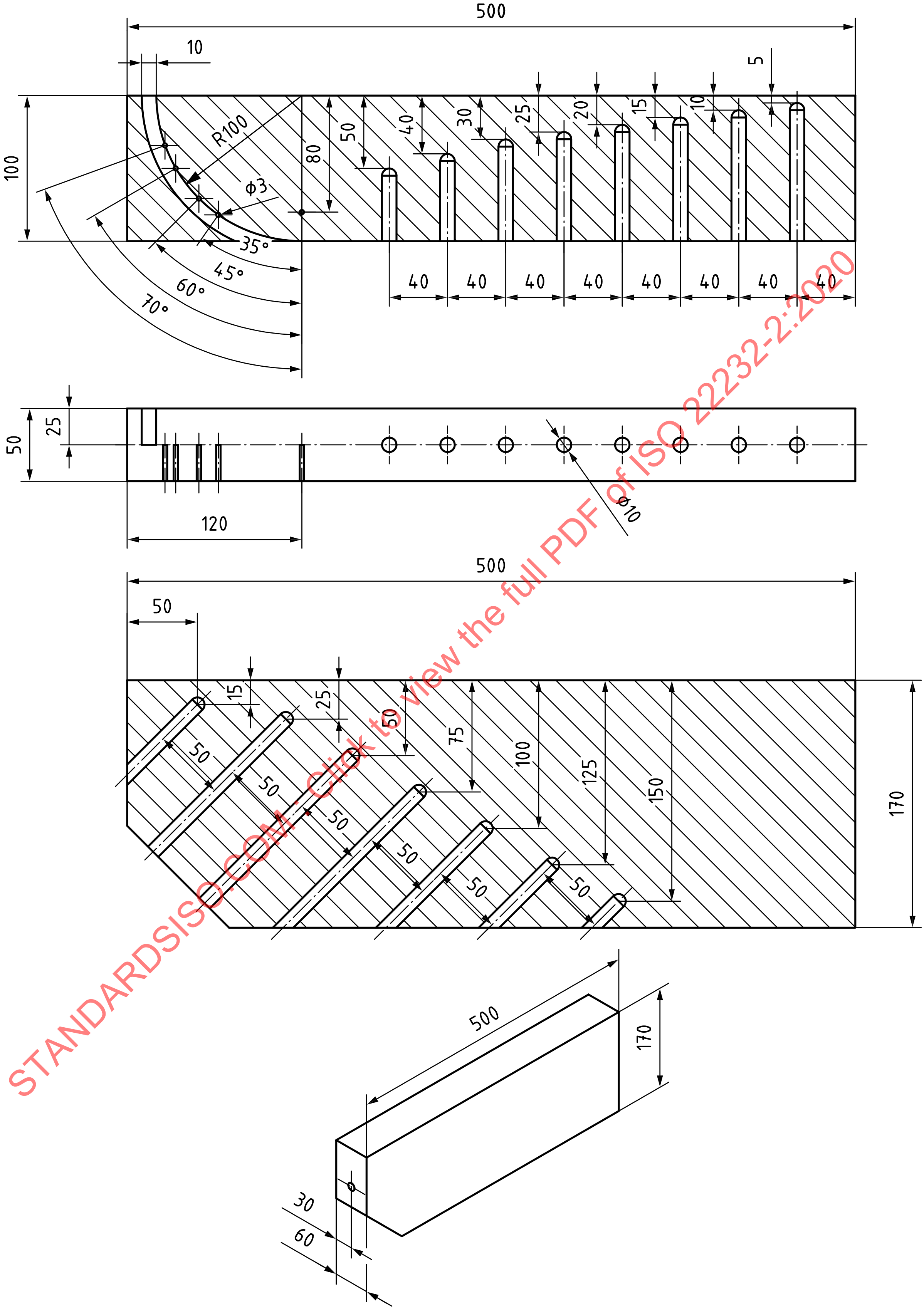


Figure 7 — Examples of test blocks with side-drilled and hemispherical-bottomed holes

e) An alternative steel block to measure index point, beam angle and beam divergence for angle-beam probes as given in Annex B.

NOTE Not all blocks are required if only special kinds of probes are to be checked, e.g. blocks to measure the index point and the beam angle are not necessary if only straight-beam probes are measured.

For measuring distances, the following equipment shall be used:

f) A ruler.

g) Feeler gauges starting at 0,05 mm.

For testing immersion probes, the following reflectors and additional equipment shall be used:

h) A steel ball or rod with a hemispheric ended smooth reflective surface. For each frequency range the diameter of ball or rod to be used is given in Table 3.

Table 3 — Steel ball (rod) diameters for different frequencies

Probe centre frequency MHz	**Diameter *d* of ball or rod** mm
$0,5 \leq f \leq 3$	$3 \leq d \leq 5$
$3 < f \leq 15$	$d \leq 3$

i) A large plane and smooth reflector. The target's lateral size shall be at least ten times wider than the beam width of the probe under test measured at the end of the focal zone, as defined in 8.6.2.4.1.

The reflector's lateral size shall be at least five times the wavelength calculated using the sound velocity of the fluid used and the centre frequency of the probe under test.

j) An immersion tank equipped with a manual or automated scanning mechanism with five free axes:

— three linear axes X, Y, Z;

— two angular axes θ and ψ.

k) Automated recording means: if the amplitudes of ultrasonic signals are recorded automatically, it is the responsibility of the manufacturer to ensure that the system has sufficient accuracy. In particular, consideration shall be given to the effects of the system bandwidth, spatial resolution, data processing and data storage on the accuracy of the results.

Typical setups to measure the sound beam of immersion probes are shown in Figures 16, 17 and 18.

The scanning mechanism used with the immersion tank should be able to maintain alignment between the reflector and the probe in the X and Y directions, i.e. within ±0,1 mm for 100 mm distance in the Z direction.

The temperature of the water in the immersion tank should be maintained at room temperature and shall not deviate by more than ±2 °C during the characterization of immersion probes described in 8.2 to 8.6.

The water temperature shall be reported in the probe data sheet.

Care shall be taken about the influence of sound attenuation in water, which, at high frequencies, causes a downshift of the echo frequency when using broad-band probes.

Table 4 shows the relation between frequency downshift and water path.

Table 4 — Frequency downshift in percent of centre frequency f_0 depending on total water path length, for relative bandwidths (Δf_{rel}) 50 % and 100 %

f_0 MHz	Δf_{rel} %	Total water path mm															
		10	20	30	40	50	60	70	80	90	100	150	200	250	300	350	400
5	50	0	0	0	0	0	0	1	1	1	1	1	2	2	2	3	3
5	100	0	1	1	1	2	2	2	3	3	3	5	6	7	9	10	11
10	50	0	1	1	1	2	2	2	3	3	3	5	6	7	9	10	11
10	100	1	3	4	5	6	7	8	9	10	11	16	21	24	28	31	34
15	50	1	1	2	3	4	4	5	6	6	7	10	13	15	18	20	23
15	100	3	6	8	10	13	15	17	19	21	23	30	37	42	47	50	54

8 Performance requirements for probes

8.1 Physical aspects

8.1.1 Procedure

The outside of the probe shall be visually inspected for correct identification, correct assembly and for physical damage which can influence its current or future reliability. In particular, for contact probes the flatness of the contact surface of the probe shall be measured using a ruler and feeler gauges.

8.1.2 Acceptance criterion

For flat-faced probes, over the whole probe face, the gap between the ruler and the probe contact surface shall not be larger than 0,05 mm.

No visible damage of the probe contact surface that could influence the ultrasonic beam is allowed.

8.2 Pulse shape, amplitude and duration

8.2.1 Procedure

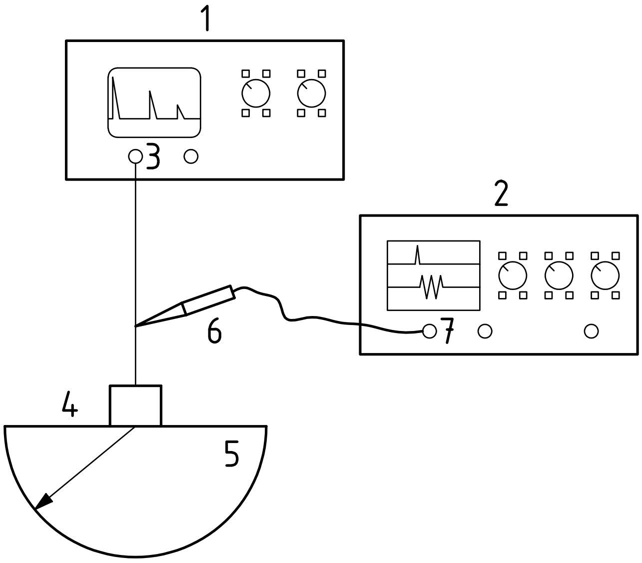
The peak-to-peak amplitude of the echo shall be measured.

The 10 % peak-to-peak amplitude value defines levels symmetrically to the base line. The first and the last crossing point of the signal with these levels define the pulse duration as shown in Figure 1. The pulse duration shall be determined with a measurement setup as shown in Figure 8 (contact probes) or in Figure 16 (immersion probes):

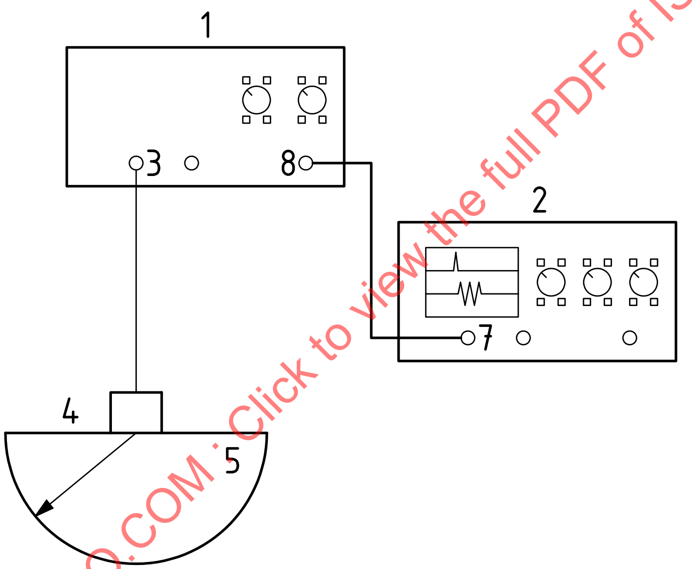
a) For contact probes with a single transducer, a hemicylindrical block or a block with parallel faces shall be used whose reflecting surface is at a distance larger than 1,5 times of the near field length of the probe or within the focal zone of focused probes.

b) For dual-transducer probes, a hemicylindrical block or a block with parallel faces shall be used whose reflecting surface is at a distance nearest to the focal point but within the focal zone of the probe.

c) For immersion probes, a large flat reflector shall be used at the focal distance for focused probes or at a distance larger than 1,5 times of the near field length for flat probes.



a) Method using an ultrasonic instrument



b) Method using an ultrasonic pulser with receiver stage

Key

1 ultrasonic a) instrument or b) pulser
2 oscilloscope
3 probe connector
4 ultrasonic probe
5 reference block
6 oscilloscope probe
7 oscilloscope input
8 pulser RF output

Figure 8 — Setup for measuring the pulse shape, amplitude and duration

It shall be stated, whether the measurement was done with wear plates, coupling membranes or other equipment mounted or not.

The pulser setting shall be recorded. It is recommended to plot the transmitter pulse shape.

8.2.2 Acceptance criterion

The pulse duration shall not be greater than the manufacturer's specification stated in the probe data sheet.

The plot of the transmitter pulse should be included in the probe data sheet.

8.3 Frequency spectrum and bandwidth

8.3.1 Procedure

The same setup as in 8.2 shall be used, but using a frequency spectrum analyser/digitiser instead of an oscilloscope and oscilloscope probe. The reflector echo shall be gated and the frequency spectrum shall be determined using a spectrum analyser or a Discrete Fourier Transform.

Spurious echoes from the probe's wedge, e.g. from the housing or the damping, shall not be analysed together with the echo from the semi-cylinder or any other appropriate calibration block. The gate width shall be twice the pulse duration as a minimum and centred on the maximum of the pulse.

The lower and upper cut-off frequencies f_l and f_u shall be determined at a 6 dB drop from the maximum value in the frequency spectrum. For the immersion technique the values shall be corrected according to Table 4.

From these upper and lower cut-off frequencies f_u and f_l, the centre frequency f_o, the bandwitdth Δf and the relative bandwidth Δf_{rel} shall be calculated as given in ISO 5577. See Formulae (1) to (3):

$$f_o = \frac{f_u + f_l}{2} \tag{1}$$

$$\Delta f = f_u - f_l \tag{2}$$

$$\Delta f_{rel} = \left(\frac{\Delta f}{f_o}\right) \times 100\,\% \tag{3}$$

8.3.2 Acceptance criteria

The measured centre frequency shall be within ±10 % of the frequency stated in the probe data sheet.

The measured −6 dB bandwidth shall be within ±15 % of the bandwidth stated in the probe data sheet.

If the spectrum between f_l and f_u has more than one maximum, the amplitude ratio between adjacent minima and maxima shall not exceed 3 dB.

8.4 Pulse-echo sensitivity

8.4.1 Procedure

Pulse-echo sensitivity is defined by Formula (4):

$$S = 20\log_{10}\left(\frac{V_{out}}{V_{in}}\right) \tag{4}$$

where

V_{out} is the peak-to-peak voltage of the echo from a specified reflector, before amplification as measured in 8.2;

V_{in} is the peak-to-peak voltage applied to the probe with the ultrasonic instrument set to separate pulser/receiver mode.

Probe sensitivity comparisons made with different types of ultrasonic instruments can vary, because the probe sensitivity is influenced by the coupling conditions and by the impedances of pulser, probe, cable and receiver. Therefore, the used equipment shall be specified in the probe data sheet.

8.4.2 Acceptance criterion

For probes manufactured in series, the pulse-echo sensitivity shall be within ±3 dB of the manufacturer's specification stated in the probe data sheet.

For individually designed or manufactured probes, the measured sensitivity shall be reported on the probe test report.

8.5 Distance-amplitude curve

8.5.1 General

The amplitude of ultrasonic pulses varies with distance from the probe. Therefore, to evaluate echoes from reflectors, for all kinds of probes, distance-amplitude curves are needed using the reflectors listed in Table 5.

Table 5 — Reflectors for distance-amplitude curves

Reflector shape	Contact technique	Immersion technique
Disk	Flat-bottomed holes	Flat-ended rods
Cylindrical	Side-drilled holes	Cylindrical rods
Spherical	Hemispherical-bottomed holes	Hemispherical-ended rods or balls

8.5.2 Procedure

When using contact probes flat-bottomed holes, side-drilled holes and hemispherical-bottomed holes are used as reflectors when using contact probes. With immersion probes, usually a small-sized steel ball is used to measure a distance-amplitude curve (see 8.6.2).

For dual-transducer probes, the axis of the side-drilled holes shall be perpendicular to the separation layer. Contoured probes should be evaluated on reference blocks having the same curvature as the sample the probe shoe was fitted to. If this is not possible, they can only be evaluated on reference blocks with flat contact surfaces before applying the contour to the probe shoe.

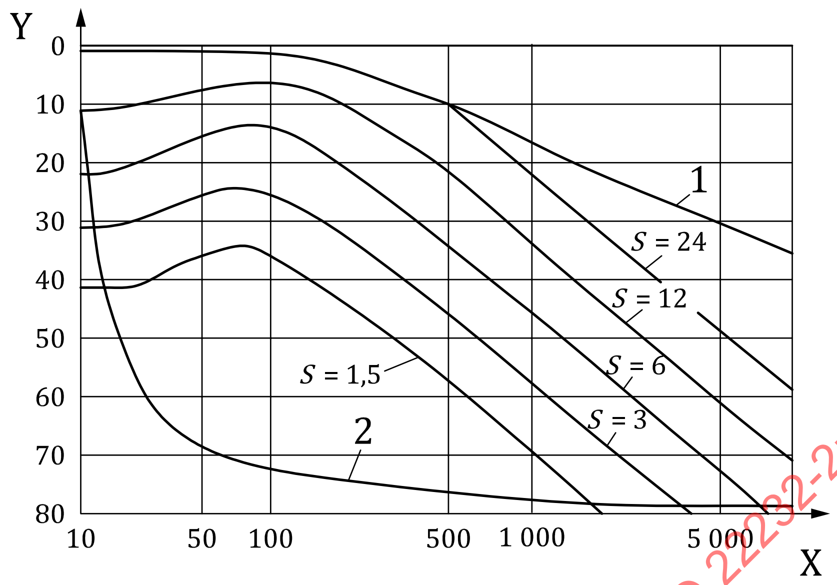
Using a series of reflectors of constant size but at different distances from the probe the received echo amplitudes shall be plotted against distance. At least eight measurement points on each curve shall be available, except for highly focused probes. The distances used shall cover the focal range of focusing probes or the range including the near field length of non-focusing probes.

Distances and amplitudes shall be determined on the calibrated screen of an ultrasonic instrument mentioned in the probe data sheet.

The distance-amplitude curve and the distance-noise curve should only be made on request of the client.

A diagram showing at least one distance-amplitude curve shall be available for each probe type, attached to the manufacturer's specification stated in the probe data sheet. This diagram shall also include a distance-noise curve.

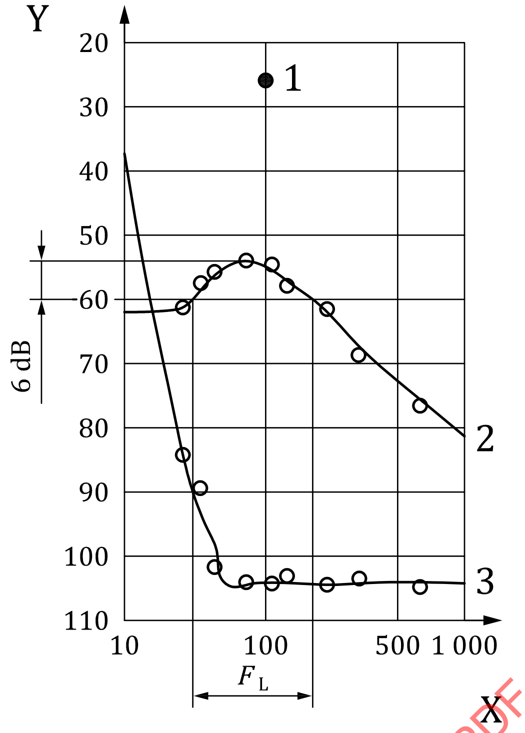
Figure 9 shows an example of different distance-amplitude curves, calculated for disk-shaped reflectors in steel (distance-gain-size diagram — DGS-diagram). Figure 10 shows an example of a measured distance-amplitude curve for 3 mm side-drilled holes in steel, with the associated distance-noise curve.



Key

1 back wall echo
2 noise level
X distance (mm)
Y gain (dB)
S reflector size (mm)

Figure 9 — Calculated distance-amplitude curves for disk-shaped reflectors in steel



Key

1 back wall echo

2 distance-amplitude curve for 3 mm side-drilled holes

3 distance-noise curve

X distance (mm)

F_L length of focal zone

Y gain (dB)

Figure 10 — Measured distance-amplitude curve for 3-mm side-drilled holes with distance-noise curve

8.5.3 Acceptance criterion

Within the focal zone the distance-amplitude curve and the distance-noise curve shall not deviate by more than 3 dB from the curves given in the manufacturer's specification stated in the probe data sheet.

8.6 Beam parameters for immersion probes

8.6.1 General

The measurement technique consists of studying the probe's sound beam in water, using a target. This target is a small, almost point source reflector, or a hydrophone receiver. The beam parameters are determined by scanning the reflector or hydrophone relative to the beam, either by moving the target or the probe.

If the target is a reflector, echo mode is used. Both transmitter and receiver characteristics of the probe are verified. If the target is a hydrophone transmission mode is used, and then only the transmitting characteristics of the probe is verified.

The same reflector or hydrophone shall be used for all the beam parameter measurements associated with one particular probe.

Small variations in the measured position of maximum signals occur as measured by a hydrophone or different reflector types. Consequently, for reasons of repeatability, the equipment and the parameters of the target used shall be recorded with the results.

Targets are listed in 7.1 and 7.2, h).

Settings of the ultrasonic instrument or pulser/receiver (pulse energy, damping, bandwidth, gain) shall be the same as those defined in 8.2. However, if the settings are changed during the measurement (gain for example), the new values shall be recorded on the result sheet.

Two equitable procedures are given for beam measurements. They differ only in the methods used to record the measurement results:

a) Direct measurement of specific beam parameters:

   This technique, described in 8.6.2, is based on direct readings at specific points within the beam (see Figures 11 to 15).

b) Measurements performed with an automated scanning system:

   This technique, described in 8.6.3, is based on the automated collection of data during scanning. If measurement results of the beam parameters are provided, the C-Scan image shall be provided. This copy shall include a scale of the acoustic levels defined in 8.6.3.

Before performing beam measurements described below, the squint angle shall be compensated for, by setting the beam axis perpendicular to the *XY*-plane as shown on Figures 16, 17 and 18. This operation is performed by adjusting both angles θ and ψ of the probe holder to maximize the echo from a flat target in the *XY*-plane.

8.6.2 Beam profile — Measurements performed directly on the beam

8.6.2.1 General

Either one of the following methods shall be used to record the ultrasonic peak echo voltage:

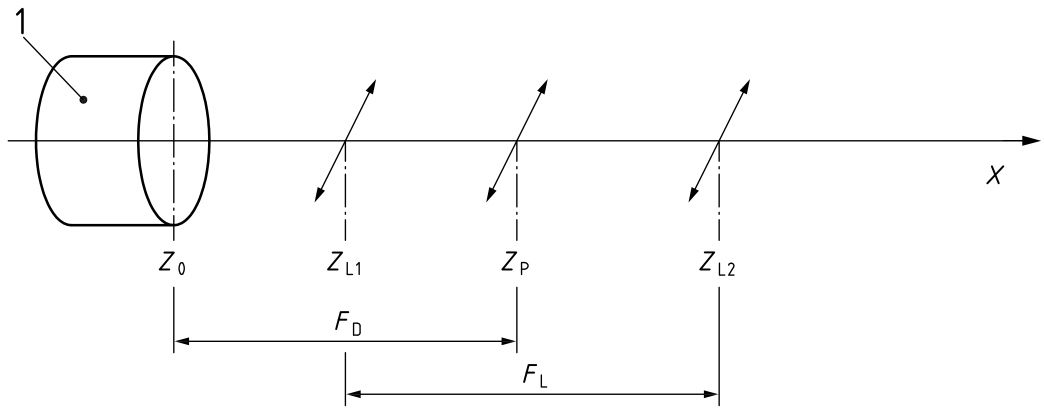
a) manual recording of the amplitude displayed on an oscilloscope;

b) automated recording of the amplitude synchronized to the scanner movement.

In this last case, the focal distance, the focal length, the focal width, the transverse profile and the beam divergence shall be deduced from the graphs obtained.

Figure 17 shows the equipment setup used when the target is a ball reflector and Figure 18 shows the equipment used when the target is a hydrophone.

The focal distance and the focal length (see Figure 11) shall be determined from axial profiles (see Figure 12 and 13) and the focal width and beam divergence are measured from transverse profiles (see Figure 14 and 15).



Key

1 probe

X distance (mm)

F_D focal distance

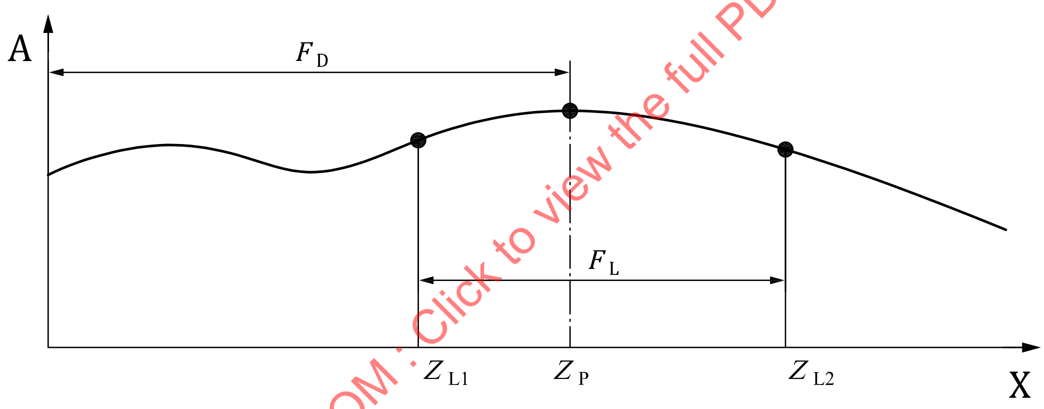
Z_o sound exit point

Z_{L1}, Z_{L2} boundaries of focal zone

F_L length of focal zone

Z_P focal point

Figure 11 — Significant points on the beam axis of immersion probes



Key

A amplitude (dB)

X distance (mm)

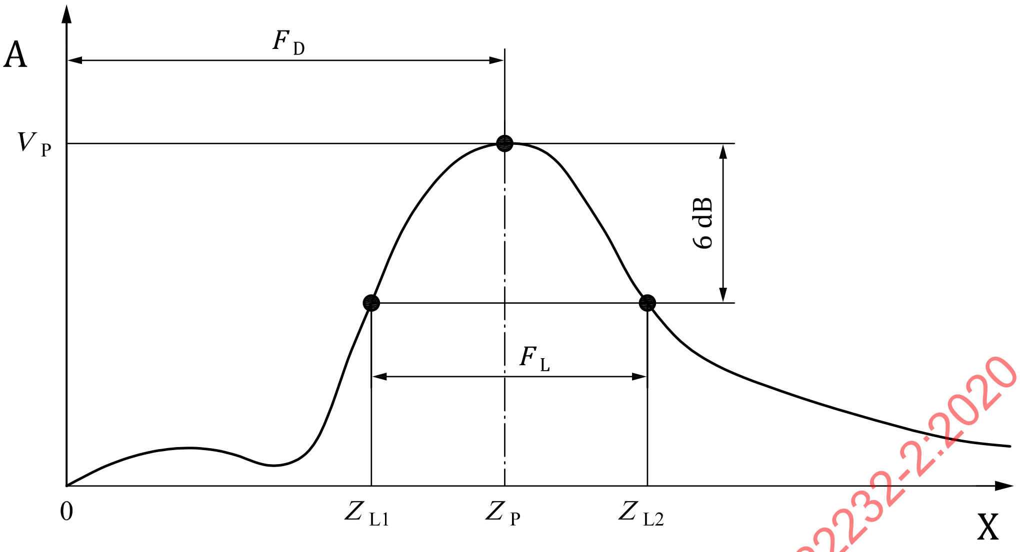
F_D focal distance

Z_{L1}, Z_{L2} boundaries of focal zone

F_L length of focal zone

Z_P focal point

Figure 12 — Axial profile of a non-focused immersion probe



Key

A amplitude (dB)

X distance (mm)

F_D focal distance

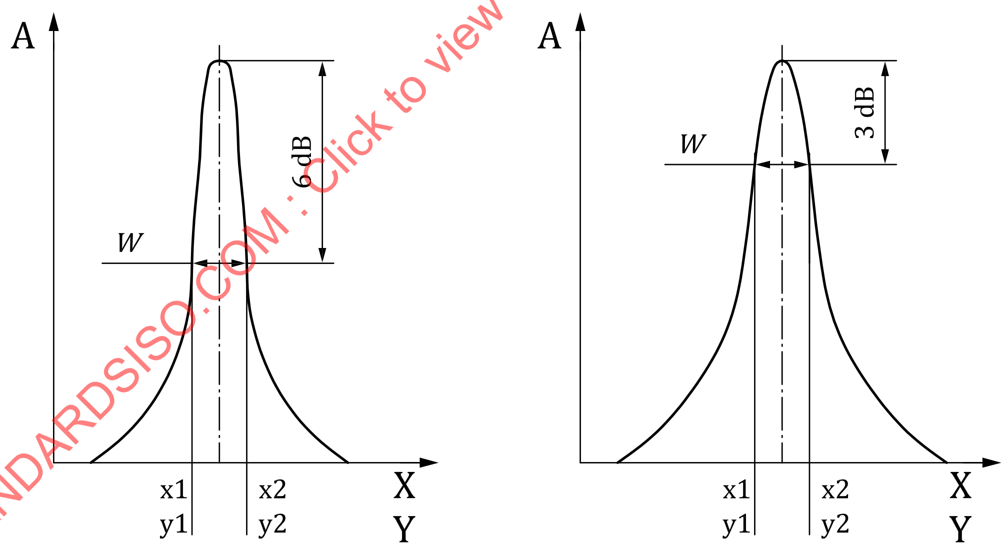
V_P amplitude at focal distance

Z_{L1}, Z_{L2} boundaries of focal zone

F_L length of focal zone

Z_P focal point

Figure 13 — Axial profile of a focused immersion probe



a) Pulse-echo technique **b) Hydrophone technique**

Key

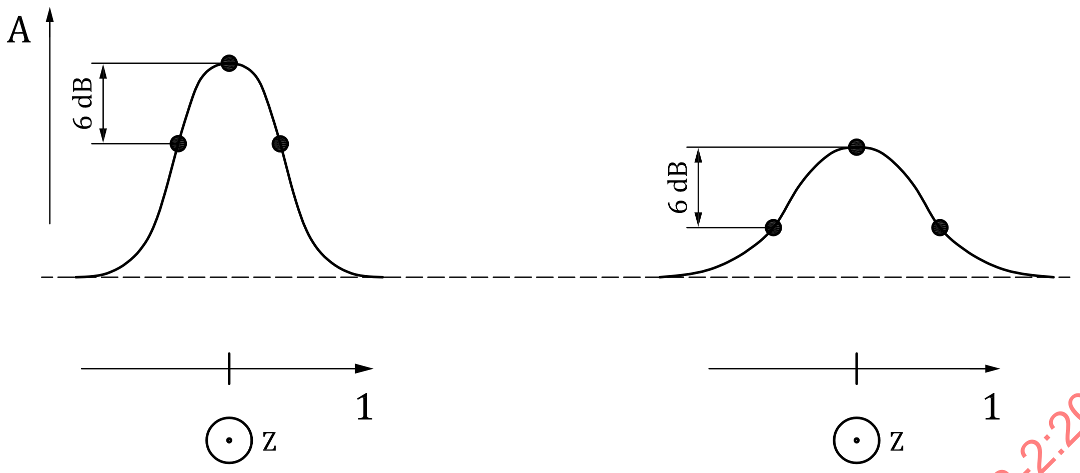
X, Y *X* or *Y* axis

A amplitude

W focal width

x1, x2, y1, y2, coordinates on X- and Y-axis

Figure 14 — Transverse profiles of immersion probes



a) At the focal point

b) At the far end of the focal zone

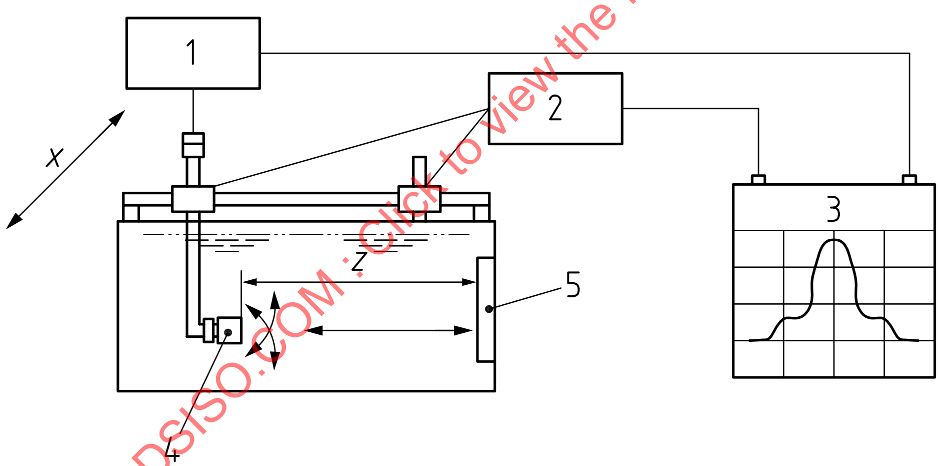
Key

1 X or Y axis

A amplitude

Z Z axis (in sound path direction)

Figure 15 — Transverse profiles in the focal zone of an immersion probe



Key

1 ultrasonic instrument

2 positioning interface

3 display

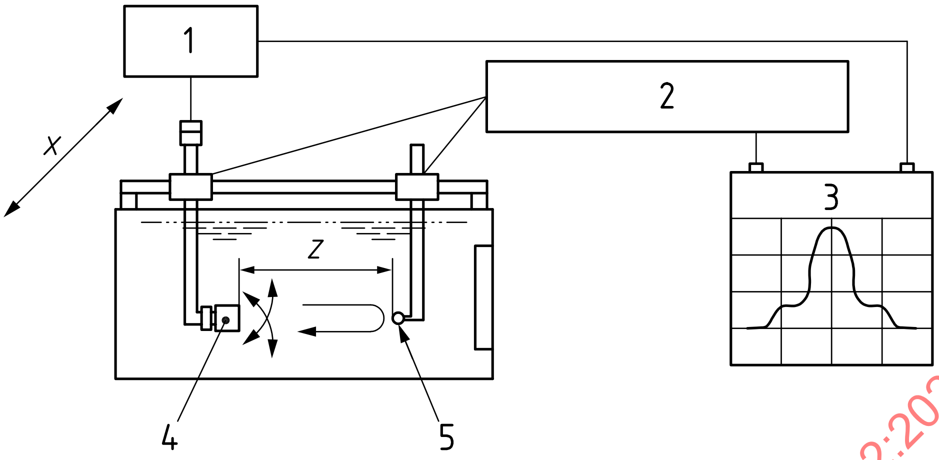
4 probe

5 plate reflector

X lateral position

Z sound path in water

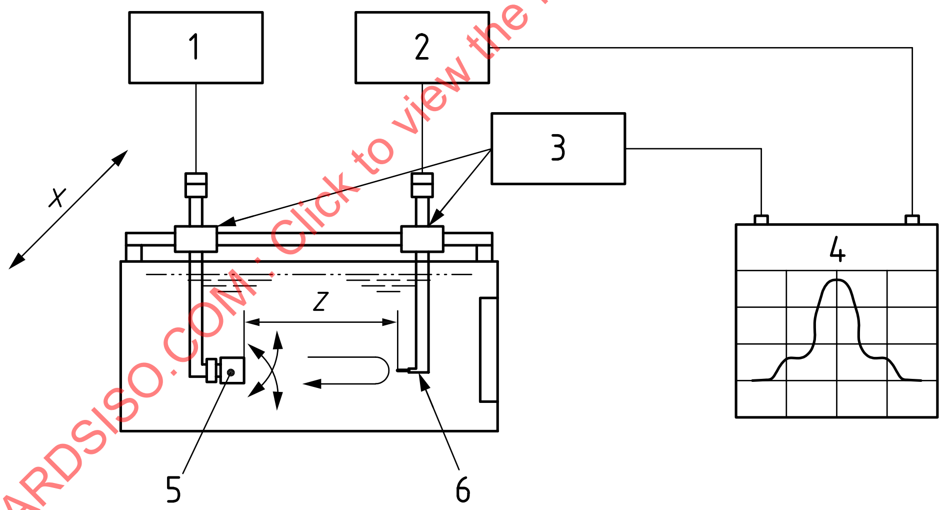
Figure 16 — Setup to measure the sound beam of immersion probes — Adjustment of the beam axis



Key

1	ultrasonic instrument	*X*	lateral position
2	positioning interface	*Z*	sound path in water
3	display		
4	probe		
5	ball reflector		

Figure 17 — Setup to measure the sound beam of immersion probes using a ball reflector



Key

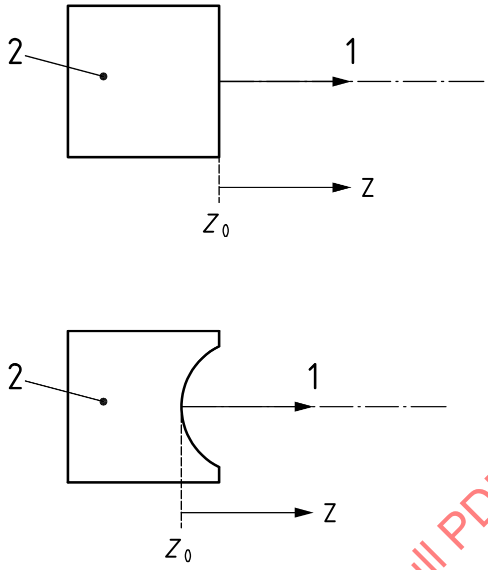
1	ultrasonic instrument	6	hydrophone
2	hydrophone receiver	*X*	lateral position
3	positioning interface	*Z*	sound path in water
4	display		
5	probe		

Figure 18 — Setup to measure the sound beam of immersion probes using a hydrophone

8.6.2.2 Axial profile — Focal distance and length of the focal zone

8.6.2.2.1 Procedure

The target shall be placed on the probe axis and the target and the probe shall be placed in contact. The coordinate of the front face of the probe or its acoustic lens is Z_0, see Figure 19.



Key

1 beam axis

2 probe

Z distance

Z_0 zero point

Figure 19 — The point Z_0 of the coordinate system for immersion probes

The target (or probe) shall be moved along the Z-axis, increasing probe-target distance. The distance at which the signal is maximized shall be determined, see Figures 11, 12 and 13.

X- and Y-positions shall be adjusted to further maximize the signal amplitude. The related distance coordinate is Z_p and the related voltage is V_p.

The focal distance is given by Formula (5):

$$F_D = |Z_p - Z_0| \tag{5}$$

By increasing and reducing the distance between the probe and the target the limits of the focal zone shall be found, i. e. the two points where V_p is reduced by 6 dB, if a reflector is used, or by 3 dB, if a hydrophone is used. Z_{L1} and Z_{L2} are the coordinates of these points on the Z-axis.

The length of the focal zone is given by Formula (6):

$$F_L = |Z_{L2} - Z_{L1}| \tag{6}$$

8.6.2.2.2 Acceptance criteria

The focal distance and length of the focal zone shall be within ±15 % of the manufacturer's specifications stated in the probe data sheet.

8.6.2.3 Transverse profile — Focal width

8.6.2.3.1 Procedure

The same setup and the same mechanical settings as in 8.6.2.2.1 shall be used. The target shall be placed at the focal point of the probe, as found in 8.6.2.2.1.

To measure the focal width in the X direction the probe (or hydrophone) shall be moved in the X direction to find the two points X_1 and X_2, where the amplitude from the target has decreased by 6 dB (by 3 dB when a hydrophone is used).

To measure the focal width in the Y direction the X position shall be returned to the focal point and the measurement shall be repeated, but this time with movement in the Y direction to find the two points Y_1 and Y_2, where the amplitude of the signal from the target has decreased by 6 dB (by 3 dB when a hydrophone is used).

Both beam widths on X-axis and on Y-axis at focal point (see Figure 15) are given by the differences according to Formula (7):

$$W_{X1} = |X_2 - X_1|$$

$$W_{Y1} = |Y_2 - Y_1| \quad (7)$$

8.6.2.3.2 Acceptance criterion

Both focal widths shall be within ±15 % of the manufacturer's specifications stated in the probe data sheet.

8.6.2.4 Transverse profile — Beam divergence

8.6.2.4.1 Procedure

The measurement of the beam divergence is only required for probes that have no artificial focusing means, such as acoustic lenses or curved piezoelectric transducers, see Figure 12. The beam divergence shall be deduced from the measurement of the beam width, as defined in 8.6.2.3, but measured in the far field, see Figure 14.

The measurement shall be performed as follows:

a) the beam widths W_{X1} and W_{Y1} at the focal distance as described in 8.6.2.3.1 shall be measured first;

b) the target (or probe) then shall be placed at the far end of the focal zone (Z_{L2}), as measured in 8.6.2.2.1.

The corresponding values X'_1, X'_2 and Y'_1, Y'_2 shall be recorded, i. e. the target (or probe) positions on X-axis and on Y-axis where the peak voltage decreases by 6 dB (reflector) or 3 dB (hydrophone) from the maximum value V_L, which is obtained on the beam axis.

The beam widths at the end of the focal zone (see Figure 14) are given by Formula (8):

$$W_{X2} = |X'_2 - X'_1|$$

$$W_{Y2} = |Y'_2 - Y'_1| \quad (8)$$

The angles of beam divergence in X and Y directions are calculated using Formula (9):

$$\Omega_X = \arctan \frac{W_{X2} - W_{X1}}{2(Z_{L2} - Z_p)}$$
$$\Omega_Y = \arctan \frac{W_{Y2} - W_{Y1}}{2(Z_{L2} - Z_p)} \quad (9)$$

8.6.2.4.2 Acceptance criterion

The angles of divergence shall not differ from the manufacturer's specified values as stated on the probe data sheet by either ±10 % or by 1°, whichever is larger.

8.6.3 Beam profile — Measurements made using an automated scanning system

8.6.3.1 General

The ultrasonic echo peak voltage shall be recorded in different planes during an automated scan of the probe (or the reflector). The variations of amplitude with position shall be recorded under the following conditions:

a) The sensitivity, the amplitude resolution of data processing, the motion speed and the motion resolution shall be sufficient to avoid any loss of information.

   The system shall have sufficient dynamic range to collect the high-amplitude signals (obtained at the focal point) without saturation and the low-amplitude signals with a sufficient signal-to-noise ratio.

b) The maximum peak voltage V_p, detected at the focal point, defines the 0 dB level. The coding used for the 0 dB, −3 dB, −6 dB, −12 dB levels shall appear on a scale on the scan recording.

   The verification is based on performing three scans:

c) One scan in the *XZ*- or *YZ*-plane shall be performed including the beam axis to determine the focal distance and the length of the focal zone;

d) Two scans shall be performed in the transverse plane *XY* at the focal distance and at the far end of the focal zone. These scans provide the focal width and the beam widths in the X and Y directions. The angles of beam divergence shall be calculated from the beam widths measured in the *XY*-plane.

8.6.3.2 Beam profile by scanning means — Focal distance and focal length

8.6.3.2.1 Procedure

The same setup as described in Figure 17 shall be used when the target is a reflector and when the target is a hydrophone Figure 18 applies.

The focal distance and the length of focal zone shall be deduced from the scans in the plane containing the beam axis.

The scanner shall be adjusted so that:

a) its motion plane contains the beam axis;

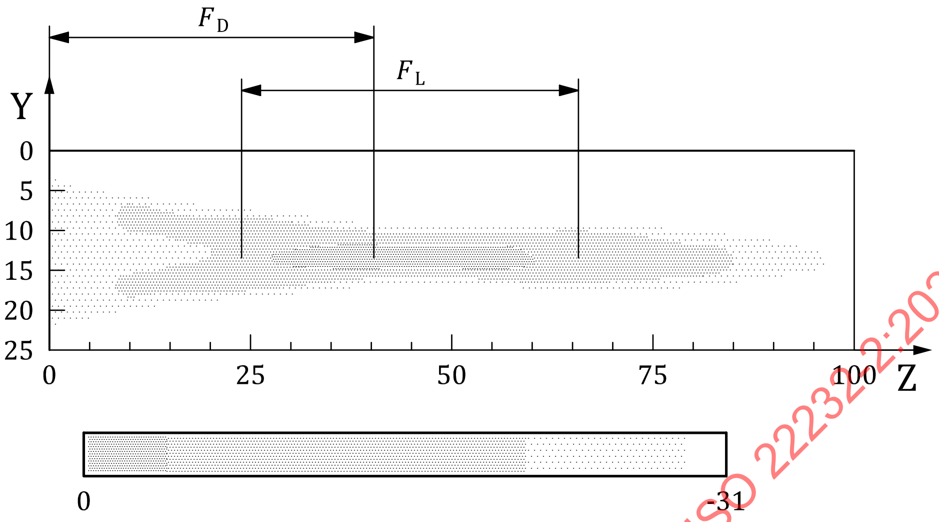
b) the *XZ*- or *YZ*-plane covered by the scanning is wide enough to include the ends of the focal zone and the two points of transverse axes (X and Y) where the amplitude is 6 dB (reflector) or 3 dB (hydrophone) lower than on the beam axis.

From the images the following parameters shall be determined:

c) the focal distance F_D, as defined in 8.6.3.2;

d) the length of the focal zone F_L, as defined in 8.6.3.2.

An example of this plot is given in Figure 20.



Key

F_D	focal distance (mm)
F_L	length of focal zone (mm)
Z	distance on beam axis (mm)
Y	distance perpendicular to beam axis (mm)
Gray scale	amplitude value in dB, with 0 dB as maximum amplitude

Figure 20 — C-scan image of the sound beam profile of a non-focusing immersion probe

8.6.3.2.2 Acceptance criteria

The focal distance and the length of the focal zone shall be within ±15 % of the manufacturer's specification stated in the probe data sheet.

8.6.3.3 Beam profile by scanning means — Focal width and beam divergence

8.6.3.3.1 Procedure

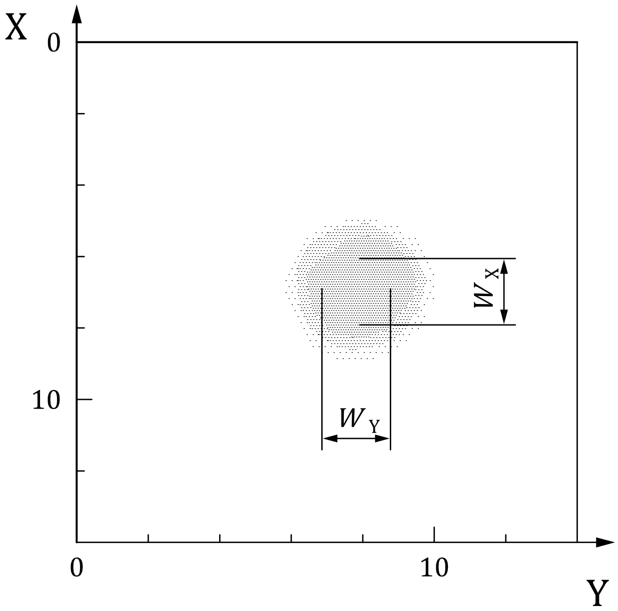
The mechanical setup is the same as in 8.6.3.2.1 and described in Figures 17 and 18.

The first scan shall be performed at the focal distance. The scanner shall be adjusted as follows:

a) The *Z*-axis of the scanner shall be adjusted so that the target is at the focal point, as it was determined in 8.6.3.2.1. The scanner displacements shall be in the *XY* plane containing the focal point and shall be perpendicular to the beam axis.

b) The *XY* scanning area shall be adjusted to include the positions where the amplitudes drop by 20 dB from V_p if using a reflector, or by 10 dB if using a hydrophone.

At the focal distance, W_{X1} and W_{Y1} shall be determined as diameters of the zones measured in the *X* or *Y* direction where the displayed amplitudes are 6 dB (reflector) or 3 dB (hydrophone) lower than the value V_p measured on the beam axis (see Figure 21 for an example).



Key

W_X	focal width on *X* axis (mm)
W_Y	focal width on *Y* axis (mm)
X, Y	distance perpendicular to beam axis (mm)
Gray scale	Amplitude value in dB, with 0 dB as maximum amplitude

Figure 21 — C-Scan image of a sound beam of a focusing immersion probe

The second scan shall be performed at the far end of the focal zone.

The mechanical setup and the bridge adjustment are the same as for the previous scanning, except that the target is placed at the far end of the focal zone (Z_{L2}), as defined in 8.6.3.2.1.

From the image the focal widths W_{X2} and W_{Y2} shall be determined by the same method used to determine W_{X1} and W_{Y1} at the focal distance.

The angles of divergence in the *X* and *Y* direction are determined by the same calculations used in 8.6.2.4.1.

8.6.3.3.2 Acceptance criteria

The angles of divergence shall not differ from the manufacturer's specified values stated on the probe data sheet by either ±10 % or by ±1°, whichever is larger.

The focal widths shall be within ±15 % of the manufacturer's specification stated in the probe data sheet.

8.7 Beam parameters for straight-beam single-transducer contact probes

8.7.1 General

The procedures given in this clause are for probes with flat contact surfaces only.

Contoured probes should be evaluated on reference blocks having the same curvature as the sample the probe shoe was fitted to. If this is not possible, they can only be evaluated on reference blocks with flat contact surfaces before applying the contour to the probe shoe.

8.7.2 Beam divergence and side lobes

8.7.2.1 Procedure

One of the following equitable methods shall be used to measure the directivity pattern:

a) Using an electromagnetic-acoustic (EMA) receiver.

The probe shall be coupled to a semi-cylinder (see Figure 22).

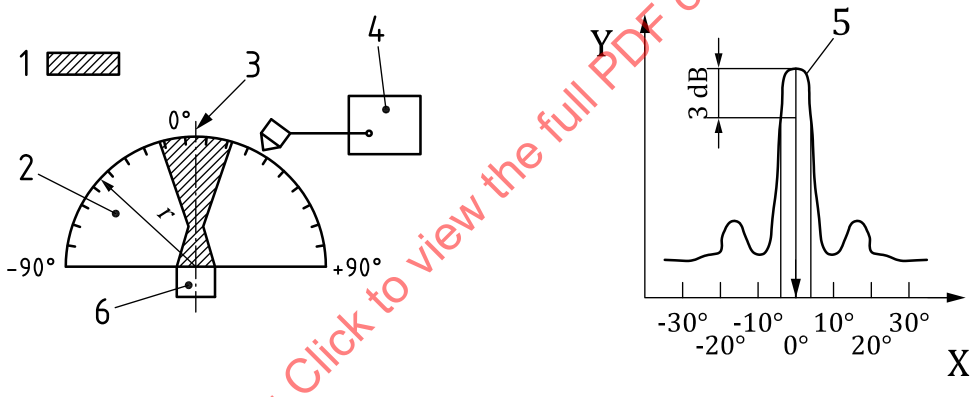
When scanning the cylindrical surface of the block the EMA receiver shall be positioned as close as possible to the surface with a constant distance to optimize the received signals signal to noise ratio.

The signal amplitude shall be plotted against the scanning angle of the EMA receiver.

The plot shall include the main lobe and the adjacent side lobes. The angles for the −3 dB positions of the main lobe give the divergence angles (Figure 22).

The angles of divergence shall be measured in two perpendicular planes.

For rectangular transducers these planes shall be parallel to the larger side a and the smaller side b of the transducer.



Key

1	sound beam	5	main lobe
2	half cylinder	6	straight-beam probe
3	beam axis	X	angle in degrees (°)
4	EMA receiver	Y	amplitude in decibels (dB)

Figure 22 — Measurement of beam divergence and beam angle

b) Using reference blocks with side-drilled holes.

Test blocks containing 3 mm side-drilled holes at various depths parallel to the test surface, as shown in Figure 4, shall be used to determine the angles of divergence and the side lobes in the two perpendicular planes of the probe by rotating the probe by 90° on the test surface.

For each hole the position of the probe to receive the maximum echo and for the forward and backward position of the 6 dB drop and side lobe positions shall be marked in a final plot.

The beam axis shall be determined as the straight line through the marks of the maximum echo together with the normal to the surface of the block. The straight lines fitted to the edge points of the beam together with the beam angle gives the 6 dB divergence angles.

Note the change in echo amplitude in relation to probe movement when the beam is scanned over each hole in turn.

If a side lobe is detected in the amplitude profile from two or more holes, the side lobe shall be maximized and its position in relation to that of the main lobe shall be plotted. Also the amplitude of the side lobe in relation to that of the main lobe shall be recorded.

c) Using reference blocks with hemispherical-bottomed holes.

Test blocks containing hemispherical-bottomed holes, maximum 10 mm diameter at various depths from the test surface, as shown in Figure 7 shall be used to determine the angles of divergence in two perpendicular planes.

This shall be done by moving the probe in two perpendicular directions if the block is wide enough or by rotating the probe by 90° on the test surface.

For each hole, the position of the probe to receive the maximum echo and for the forward and backward position of the 6 dB drop shall be marked.

8.7.2.2 Acceptance criteria

The angles of divergence shall not differ from the manufacturer's specified values stated in the probe data sheet by more than 10 % or by ±1°, whichever is larger.

Side lobes shall be ≥20 dB below the main lobe for reflection techniques and ≥10 dB below the main lobe for the EMA technique.

8.7.3 Squint angle and offset for straight-beam probes

8.7.3.1 Procedure

With straight-beam probes the offset is defined as the distance between the geometrical centre point of the probe and the measured acoustical centre point of the probe (Figure 2).

One of the following equitable methods shall be used:

a) Using an electromagnetic-acoustic (EMA) receiver.

To measure the squint angle and the offset for straight-beam probes the setup in Figure 2 shall be used.

First the probe shall be connected to the ultrasonic instrument which is switched to pulse-echo mode. By rotating and moving the probe on a semi-cylindrical block the echoes of the multiple echoes series from the block shall be maximized. This occurs when, at all reflections, the beam hits the cylindrical surface perpendicularly and the acoustical centre point of the probe is positioned on the centre line of the block.

Keeping the probe at this position, in the second step, the EMA receiver use the probe acting only as a transmitter.

By moving the EMA receiver on the cylindrical surface find the position of the maximum signal at the location where the beam hits the cylindrical surface the first time.

The measured angle is the squint angle for straight-beam probes δ.

The coordinates X_c and Y_c of the geometrical centre point of the probe together with the coordinates Y_m of the centre line of the block and X_m of the EMA receiver give the offset e according to Formula (10):

$$e=\sqrt{(X_m-X_c)^2+(Y_m-Y_c)^2} \quad (10)$$

b) Using reference blocks with side-drilled holes.

The position of the side-drilled hole (SDH) relative to a reference point of the block is used as X_m and Y_m. Connect the probe is connected to the ultrasonic instrument which is switched to pulse-echo mode.

By moving the probe perpendicular to the SDH the echo of the SDH shall be maximized. Then determine the position of the geometrical centre point of the probe, X_c or Y_c depending on the orientation of the probe or take it from the measurement of the beam axis in 8.7.2.1, b).

The offset e can be calculated using Formula (10).

Squint angles for straight-beam probes δ_x and δ_y shall be determined in the two perpendicular directions independently by geometrical calculation using X_c or Y_c depending on the orientation of the probe, $X_m = Y_m$ and the depth position of the SDH.

The resulting angle δ is calculated according to Formula (11):

$$\delta = \arctan\sqrt{tan^2\delta_y + tan^2\delta_x} \tag{11}$$

8.7.3.2 Acceptance criteria

The squint angle for straight-beam probes shall be ≤2°. The offset from the centre point of the probe shall be less than 1 mm.

8.7.4 Focal distance (near field length)

8.7.4.1 Procedure

For a non-focusing probe the focal distance is identical with the near field length. For these probes it is difficult to directly measure the focal distance. Therefore, for these probes the near field length should be calculated using the methods given in Annex A from the measured centre frequency f_0 and the measured angles of divergence $\gamma_\perp$ and $\gamma_{||}$ in two perpendicular directions.

The divergence shall be measured at the depth of the expected focal distance. Because Annex A does not take a delay path into account, alternative measurements or calculations may be used.

Focused straight-beam probes for direct contact shall be measured on reference blocks containing flat-bottomed holes or side-drilled holes of a constant diameter within the focal zone of the probe.

Reflectors of a 2 mm or 3 mm diameter shall be used to generate a distance-amplitude curve (best fit to the measurement points).

A measurement point shall be close to the peak of this curve, which gives the focal distance in the applied material. Focal distances caused by lenses or curved transducers are shorter than the near field length of a plane transducer of the same shape and frequency, unless defocusing is intentionally used.

8.7.4.2 Acceptance criterion

The focal distance shall be within ±20 % of the manufacturer's specification stated in the probe data sheet.

8.7.5 Focal width

8.7.5.1 Procedure

The focal width of focused straight-beam probes for direct contact can be determined using an EMA receiver or blocks with side-drilled holes or hemispherical-bottomed holes, analogous to 8.7.2.

The following methods shall be used:

a) Using electromagnetic-acoustic (EMA) receivers.

The probe shall be coupled to a semi-cylinder with a radius close to the focal distance of the probe. By moving the EMA on the surface in two perpendicular directions the angles of the 3 dB drop of the signal amplitude shall be determined [see 8.7.2.1, a)]. The focal widths of the probe shall be calculated using these angles together with the known radius of the block.

b) Using reference blocks with side-drilled holes.

To determine the divergence angles the probe shall be moved as shown in 8.7.2.1, b) in two perpendicular directions until the echo from a side-drilled hole close to the focal distance of the probe drops by 6 dB. This shift provides the focal widths of the beam.

c) Using reference blocks with hemispherical-bottomed holes.

To determine the divergence angles the probe shall be moved as shown in 8.7.2.1, c) in two perpendicular directions until the echo from a hemispherical-bottomed hole close to the focal distance of the probe drops by 6 dB. This shift provides the focal widths of the beam.

8.7.5.2 Acceptance criterion

The focal width shall be within ±20 % of the manufacturer's specification stated in the probe data sheet.

8.7.6 Length of the focal zone

8.7.6.1 Procedure

Determine the points where the amplitude drops by 6 dB as compared to the focal point from the distance-amplitude curve measured in 8.5 or 8.7.4.

The difference of their coordinates provides the length of the focal zone.

8.7.6.2 Acceptance criterion

The length of the focal zone shall be within ±20 % of the manufacturer's specification stated in the probe data sheet.

8.8 Beam parameters for angle-beam single-transducer contact probes

8.8.1 General

The procedures given in this clause are for probes with flat contact surfaces only.

Contoured probes should be evaluated on reference blocks having the same curvature as the sample the probe shoe was fitted to. If this is not possible, they can only be evaluated on reference blocks with flat contact surfaces before applying the contour to the probe shoe.

An example for a calibration block for angle-beam probes is given in Annex B.

8.8.2 Index point

8.8.2.1 Procedure

To measure the index point a test block with a quadrant shall be used. The radius of the quadrant shall be large enough that the reflecting cylindrical surface is in the far field of the probe.

The probe shall be adjusted so that the echo from the cylindrical surface is maximized. At this position the index point corresponds to the engraved centre line of the quadrant.

8.8.2.2 Acceptance criterion

The index point shall be within ±1 mm of the manufacturer's specification stated in the probe data sheet.

Angle-beam probes with transducer size ≤15 mm and frequencies ≤2 MHz generate a broad sound beam where the position of the maximum echo can only be measured within a tolerance of ±2 mm.

8.8.3 Beam angle and beam divergence

8.8.3.1 Procedure

Similar to the methods used for straight-beam probes in 8.7.2, one of the following methods shall be used to measure the divergence angles and side lobes of angle-beam probes:

a) Using electromagnetic-acoustic (EMA) receivers.

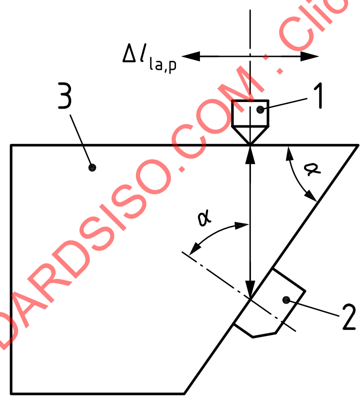
   The probe shall be coupled to a semi-cylindrical block.

   The signal amplitude shall be plotted against the scanning angle of the EMA receiver.

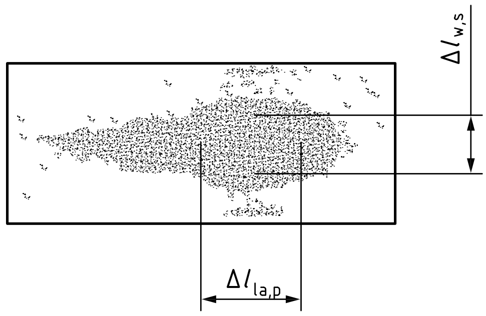
   The plot shall include the main lobe and the adjacent side lobes. The angles for the −3 dB positions of the main lobe provide the divergence angles (Figure 22).

   The angles of divergence shall be measured in two perpendicular planes (azimuthal and horizontal). The position of the maximum signal provides the angle of the beam axis (beam angle).

   Parameters of inclined beams can also be taken from a C-scan image in a plane perpendicular to the beam axis. Figure 23 shows an example of a C-scan image of a 45° angle-beam probe measured with an EMA receiver on a test block with a 45° surface.



a) Reference block



b) C-scan image

Key

1	EMA transducer	α	beam angle
2	angle-beam probe	$\Delta l_{la,p}$	projected length of focal zone
3	test block	$\Delta l_{w,s}$	projected focal width
Gray scale	amplitude value in dB, with 0 dB as maximum amplitude		

Figure 23 — Measuring beam parameters of an inclined sound beam using an EMA receiver

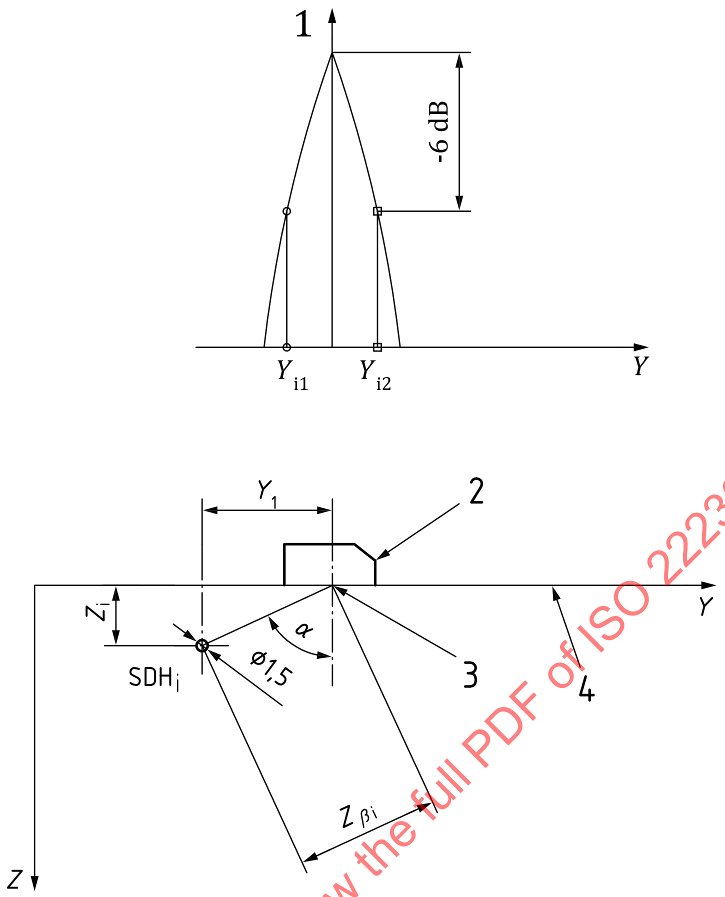
b) Using reference blocks with side-drilled holes.

A test block with a series of 3 mm side-drilled holes at different depths, as shown in Figure 4, shall be used to measure the beam angle, divergence angles and side lobes in the vertical plane.

For each hole the position of the probe to receive the maximum echo, and for the forward and backward position of the 6 dB drop and the side lobe positions shall be marked in a final plot.

The straight line through the marks of the maximum echo and the index point with the normal to the surface of the block provides the beam angle in the vertical plane. The straight lines fitted to the edge points of the beam together with the beam angle provides the −6 dB divergence angles in this plane.

An example for the longitudinal beam profile is given in Figure 24. Note the change in echo amplitude in relation to the probe movement while the beam is scanned over each hole in turn. If a side lobe is detected in the amplitude profile from two or more holes, maximize the side lobe and plot its position in relation to that of the main lobe. Also record the amplitude of the side lobe in relation to that of the main lobe.



Key

1 echo amplitude (dB)
2 angle-beam probe
3 probe index point
4 test-surface
Y length coordinate
Z depth coordinate
SDH$_i$ side-drilled hole
Y_{i1} lower position on Y axis for 6 dB drop
Y_{i2} upper position on Y axis for 6 dB drop
Z_i reflector depth
$Z_{\beta i}$ sound path
α angle of incidence

Figure 24 — Measurement of the longitudinal beam profile of an angle-beam probe

An alternative method of measuring the beam angles also using side-drilled holes is given in Annex B.

To measure the divergence angles in the horizontal plane a block with a notch is needed, as shown in Figure 6 (for 45° probes and 60° probes). The same procedure is used to determine the positions of the 6 dB drop, but the probe has to be moved laterally.

c) Using reference blocks with hemispherical-bottomed holes.

A test block with a series of the hemispherical-bottomed holes, maximum 10 mm diameter at different depths, as shown in Figure 7, shall be used to measure the beam angle and divergence angles in the vertical and horizontal planes.

For each hole the position of the probe to receive the maximum echo, and for the forward and backward position of the 6 dB drop shall be marked in a final plot.

The straight line through the marks of the maximum echo and the index point with the normal to the surface of the block provides the beam angle in the vertical and horizontal plane. The straight lines fitted to the edge points of the beam together with the beam angle provide the −6 dB divergence angles in those planes.

8.8.3.2 Acceptance criteria

For nominal beam angles up to 60° the measured value shall be within ±3° of the nominal angle for frequencies less than 2 MHz and ±2° of the nominal angle for frequencies equal to or greater than 2 MHz.

For nominal beam angles greater than 60° the measured value shall be within ±3° of the nominal angle.

The angles of divergence shall not differ from the manufacturer's specification stated in the probe data sheet by more than 10 % or by more than ±1°, whichever is the larger.

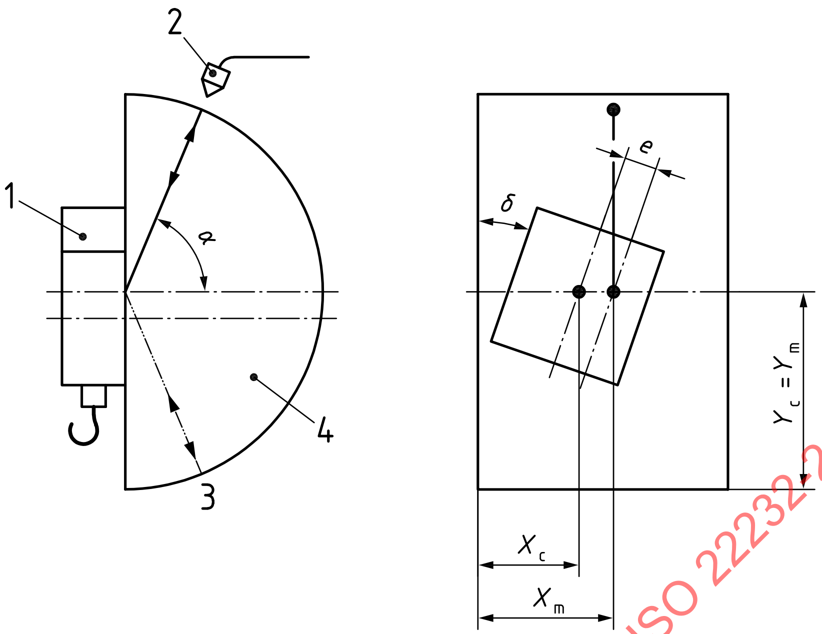
When using the reflection technique, the side lobes amplitudes shall be ≥20 dB below the main lobes amplitudes for nominal beam angles between 45° and 65°, and ≥15 dB for higher nominal beam angles.

When using the EMA technique, the side lobes amplitudes shall be ≥10 dB below the main lobes amplitudes for nominal beam angles between 45° and 65°, and ≥8 dB for higher nominal beam angles.

8.8.4 Squint angle and offset for angle-beam probes

8.8.4.1 Procedure

With angle-beam probes the offset is defined as distance between the geometrical centre line of the probe and the measured beam direction of the probe (Figure 25).



Key

1	ultrasonic angle-beam probe	*e*	offset
2	EMA receiver	*δ*	squint angle for angle-beam probes
3	echo point	X_c, Y_c	coordinates of the centre of the probe
4	hemicylindrical test block	X_m	coordinate of EMA receiver
α	beam angle	Y_m	coordinate of the centre of the block

Figure 25 — Squint angle and offset for an angle-beam probe

The squint angle shall be checked for all angle-beam probes. The offset shall only be checked if a possible deviation larger than specified in the acceptance criteria 8.8.4.2 is to be expected.

One of the following equitable methods shall be used:

a) Using an electromagnetic-acoustic (EMA) receiver.

To measure the squint angle and the offset for an angle-beam probe the same setup shall be used as in 8.7.3 (Figure 25). The squint angle δ is defined as the angle between the reference side of the probe and the measured beam axis projected onto the coupling surface (Figure 25).

First the probe shall be coupled to a semi-cylindrical block and the ultrasonic instrument shall be switched to echo mode.

By turning and moving the probe the echoes of the multiple echo series from the block shall be maximized.

Then, at all reflections, the beam hits the cylindrical surface perpendicularly and the index point of the probe is on the centre line of the block.

At this position the angle between the sides of the probe and the sides of the block provide the squint angle.

Secondly the EMA receiver shall be used (the probe acting as a transmitter only). By moving the EMA receiver the position of the maximum signal shall be determined where the beam hits the cylindrical surface for the first time.

Using Formula (12) the offset *e* shall be calculated as:

$$e=(X_m - X_c)\cos\delta \qquad (12)$$

where

X_m is the coordinate of the position of the EMA receiver

X_c is the coordinate of the intersection point of the centre line of the block with the designed beam path

For probes with an intended high squint angle, e.g. for the detecting transverse discontinuities, X_c is the coordinate of the intersection point of the centre line of the block with the theoretical beam path (not necessarily parallel to its reference side). In that case the offset e shall be calculated using the deviation from the intended beam path in Formula (12) instead of using squint angle δ to the reference side of the probe.

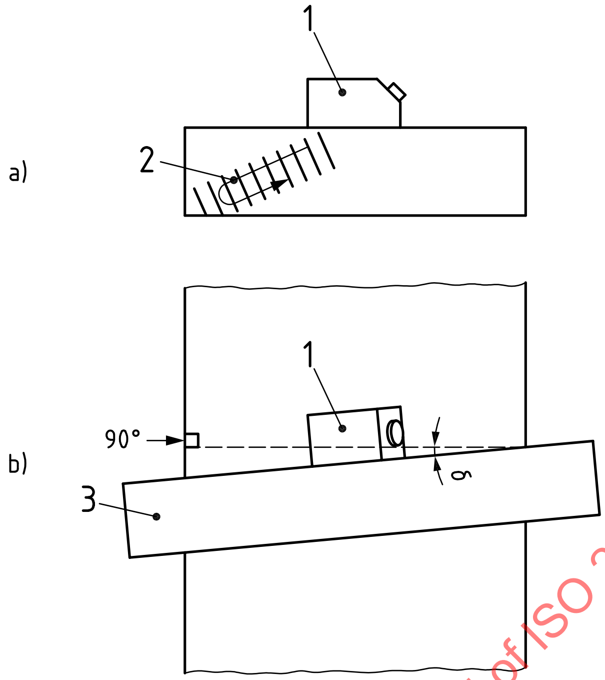
b) Using reference blocks.

With side-drilled holes, only the squint angle can be measured according to 8.7.3.1.

Adjust the position of the probe on the large flat surface of a suitable block to maximize the direct echo from a straight corner of the block, as shown in Figure 26. The corner reflector shall be in the far field of the probe.

Measure the direction in which the probe's reference side is pointing relative to the normal to the corner face by means of a straight edge and a protractor. This measurement provides the squint angle δ.

If the squint angle exceeds 1° on the first measurement, make a total of three measurements and take the mean value.



Key

1 probe
2 sound beam
3 ruler
δ squint angle

a) side view
b) top view

Figure 26 — Measuring the squint angle using the corner of a calibration block

8.8.4.2 Acceptance criteria

The squint angle shall be ≤2°. The offset shall be ≤1 mm from the centre line of the probe.

8.8.5 Focal distance (near field length)

8.8.5.1 Procedure

Similar methods to those for straight-beam probes shall be applied here (see 8.7.4). For unfocused angle-beam probes the near field length shall be calculated using the measured values of the centre frequency f_0 and beam divergence angles $\gamma_\perp$ and $\gamma_\parallel$ using the Formulae given in Annex A.

The divergence angles shall be measured at the depth of the expected focal distance. Because Annex A does not take a delay path into account, alternative measurements or calculations may be used.

With focused angle-beam probes for direct contact the same methods as for straight-beam probes shall be used (see 8.7.5).

A distance-amplitude curve shall be generated with at least eight measurement points using small flat-bottomed, hemispherical-bottomed or side-drilled holes is used. The point of peak amplitude provides the focal distance.

It is recommended that the measurement points are within the focal zone of the transducer with a measurement point close to the peak amplitude.

They shall cover the 6 dB drop compared to the peak amplitude.

Focal distances caused by lenses or curved transducers are shorter than the near field length of a plane transducer of the same shape and frequency, unless defocusing is intentionally used.

8.8.5.2 Acceptance criterion

The focal distance shall be within ±20 % of the manufacturer's specification stated in the probe data sheet.

8.8.6 Focal width

8.8.6.1 Procedure

The focal widths shall be measured in a similar way to the angles of divergence (see 8.7.2) using an EMA receiver, side-drilled holes, or hemispherical-bottomed holes.

The measurement shall be made in two perpendicular directions with one of the following methods:

a) Using electromagnetic-acoustic (EMA) receivers.

   The probe shall be coupled to a semi-cylinder whose radius is close to the focal distance of the probe. By moving the EMA probe on the surface the points are determined where the signal amplitude drops by 3 dB compared to the peak amplitude.

   With these angles and the known radius of the block the beam width at the focal distance shall be calculated.

b) Using reference blocks with side-drilled holes.

   As described in 8.8.3.1, b) the probe shall be moved until the echo from a side-drilled hole at the focal distance drops by 6 dB. This shift provides the focal widths of the beam in the vertical direction.

   The focal width in the horizontal plane can only be measured using the method described in 8.9.5.1, b).

c) Using reference blocks with hemispherical-bottomed holes.

   As described in 8.8.3.1, c), the probe shall be moved until the echo from a hemispherical-bottomed hole at the focal distance drops by 6 dB. This shift provides the focal widths of the beam in the vertical and horizontal direction.

8.8.6.2 Acceptance criterion

The focal widths shall be within ±20 % of the manufacturer's specification stated in the probe data sheet.

8.8.7 Length of the focal zone

8.8.7.1 Procedure

From the distance-amplitude curve measured in 8.5 or 8.7.5 the points are determined where the amplitude drops by 6 dB compared to the focal point. The difference of their coordinates gives the length of the focal zone.

8.8.7.2 Acceptance criterion

The length of the focal zone shall be within ±20 % of the manufacturer's specification stated in the probe data sheet.

8.9 Beam parameters for straight-beam dual-transducer contact probes

8.9.1 General

The procedures given in this subclause are for probes with flat contact surfaces only.

Contoured probes should be evaluated on reference blocks having the same curvature as the sample the probe shoe was fitted to. If this is not possible, they can only be evaluated on reference blocks with flat contact surfaces before applying the contour to the probe shoe.

8.9.2 Delay line delay path

For straight-beam dual-transducer contact probes the echo out of a test block with a quadrant, a hemicylindrical block or a block with parallel faces shall be used whose reflecting surface is at a distance nearest to the focal point but within the focal zone. If a test block with a quadrant or a hemicylindrical block is used, the probe shall be optimized in position to obtain the maximum signal from the curved surface of the block.

Set the horizontal axis of the display to sound path mode, using the sound velocity of the test block. Set the position of the transmitting pulse to the zero position on the horizontal axis of the display. Read the position of the echo from the reflecting surface of the block, then subtract the distance in the test block to obtain the delay path of the delay line. The delay line delay path is expressed in mm material equivalent (e. g. steel) as near field equivalent sound path. A method for the determination of the delay path is given in Annex C.

8.9.3 Focal distance

8.9.3.1 Procedure

The point of maximum amplitude in the distance-amplitude-curve according to 8.5 is defined as the focal distance.

The echo heights from reflectors (see Table 5) at distances within the expected focal zone shall be used to establish a distance-amplitude curve (with at least eight points).

The separation layer of the probe shall be perpendicular to the axis of the side-drilled holes.

8.9.3.2 Acceptance criterion

The position of the maximum echo shall be within ±20 % of the manufacturer's specification stated in the probe data sheet.

8.9.4 Axial sensitivity range (focal zone)

8.9.4.1 Procedure

From the curve measured in 8.6.2.2, the −6 dB points shall be determined.

8.9.4.2 Acceptance criterion

The axial sensitivity range (length of the focal zone) shall be within ±20 % of the manufacturer's specification stated in the probe data sheet.

8.9.5 Lateral sensitivity range (focal width)

8.9.5.1 Procedure

To determine the lateral sensitivity range one of the following methods shall be used:

a) Using an electromagnetic-acoustic (EMA) receiver.

This test uses the same setup as that used for single-transducer probes (see 8.8.3).

The beam profile for each transducer shall be measured separately and the combined profile shall be calculated from the product of the two beam profiles.

Select a semi-cylindrical test block with its radius close to the focal distance of the probe under test.

Operating each transducer of the probe in turn, scan the EMA receiver over the cylindrical surface of the test block.

Record the amplitudes of the signals from the two transducers for each position within the beam profile.

At each point within the beam multiply (dB values shall be added) the amplitudes measured for each transducer.

These products give the directional pattern of the dual-transducer probe.

The −6 dB boundaries of the combined beam occur where these products are reduced by a 6 dB drop from the maximum.

The measurement shall be made in two perpendicular directions, parallel and perpendicular to the separation layer of the probe.

b) Using test blocks with 3 mm side-drilled holes.

A test block shall be used which has a 3 mm side-drilled hole close to the position of the focus of the probe.

The probe shall be shifted on the coupling surface until the echo of the side-drilled hole drops by 6 dB.

These positions of the probe provide the −6 dB focal width perpendicular to the beam axis.

The scanning shall be done parallel and perpendicular to the separation layer of the probe to give two perpendicular focal widths.

c) Using test blocks with hemispherical-bottomed hole.

A test block shall be used which has a hemispherical-bottomed hole, maximum 10 mm diameter, close to the position of the focus of the probe.

The probe shall be shifted on the coupling surface until the echo from the hemispherical-bottomed hole drops by 6 dB.

These positions of the probe provide the −6 dB focal width perpendicular to the beam axis.

The scanning shall be done parallel and perpendicular to the separation layer of the probe to give two perpendicular focal widths.

8.9.5.2 Acceptance criterion

The width of the focal zone parallel and perpendicular to the separation layer shall be within ±20 % of the manufacturer's specification stated in the probe data sheet.

8.10 Beam parameters for angle-beam dual-transducer contact probes

8.10.1 General

The procedures given in this subclause are for probes with flat contact surfaces only.

Contoured probes should be evaluated on reference blocks having the same curvature as the sample the probe shoe was fitted to. If this is not possible, they can only be evaluated on reference blocks with flat contact surfaces before applying the contour to the probe shoe.

For angle-beam dual-element contact probes that generate waves on or along the object surface, e.g. creeping waves or Rayleigh waves, a notch at the contact surface shall be used in 8.10.5 (focal distance), 8.10.6 (length of the focal zone) and 8.10.7 (focal width).

8.10.2 Index point

8.10.2.1 Procedure

The index point shall be determined using a test block as for a single-transducer angle-beam probe (see 8.8.2).

8.10.2.2 Acceptance criterion

The index point shall be within ±1 mm of the point marked by the manufacturer.

8.10.3 Beam angle and profiles

8.10.3.1 Procedure

The beam angle of a dual-transducer probe shall be determined using an EMA receiver, reflecting side-drilled holes or hemispherical-bottomed holes:

a) Using an electromagnetic-acoustic (EMA) receiver.

   This test uses the same setup as that for single-transducer probes (see 8.8.3). The beam profile of each transducer of the probe shall be measured separately and the combined profile shall be calculated from the product of the two beam profiles.

   Operating each transducer in turn, scan the EMA receiver over the cylindrical surface of the test block.

   Record the amplitudes of the signals from the two transducers for each position within the beam profile.

   At each point within the beam multiply the measured amplitudes (dB values are added) for the two transducers.

   These products give the directional pattern of the dual-transducer probe.

   The 6 dB angles of divergence for the beam occur where these products are reduced by 6 dB from the maximum.

   The beam angle shall be calculated from the arithmetic mean of the angles of divergence.

b) Using side-drilled holes of 3 mm diameter.

   The same setup as for a single-transducer probe shall be used (see 8.8.3).

c) Using hemispherical-bottomed holes, maximum 10 mm diameter.

   The same setup as for a single-transducer probe shall be used (see 8.8.3).